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Advisory Circular

Subject: FLIGHT TEST GUIDE FOR CERTIFICATION OF TRANSPORT CATEGORY AIRPLANES

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1. PURPOSE. This change provides updated guidance material to ensure consistent application of certain airworthiness requirements adopted by recent amendments to 14 CFR part 25. Changed material is indicated in the margins by asterisks and at the top of each changed page with the change number and date. New material on pages 80-l through 80-28 is indicated by the change number and date only. Some text, although not changed, has been rearranged to accommodate new material.

2. PRINCIPAL CHANGES.

a. New guidance regarding an acceptable means of compliance with the wet runway and worn brake requirements adopted by Amendment 25-92, Improved Standards for Determining Rejected Takeoff and Landing Performance.

b. Additional guidance regarding criteria for locating the gate when the airplane has multiple go-around configurations, for compliance with the gate design requirements adopted by Amendment 25-98, Revision of Gate Requirements for High-Lift Device Controls.

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Section 2. PERFORMANCE

9. GENERAL - § 25.101

a. Explanation - Engine Behavior. Section 25.101(c) requires that airplane "performance must correspond to the propulsive thrust available under the particular ambient atmospheric conditions, the particular flight conditions. . . ." Therefore, engine parameter evaluations, engine torque, thrust lapse, propeller thrust, and throttle sensitivity, especially with the Electronic Control Unit off (if installed), should be accounted for at all altitudes up to and including the maximum approved takeoff altitude.

b. Procedures. This aspect of the rule may be accomplished by actual flight test, with approved takeoff ratings, at the maximum desired takeoff altitude, or with acceptable parameter variation analysis associated with tests conducted at less than the maximum objective takeoff altitude.

(1) One acceptable method of demonstrating high altitude engine operability and performance is to simulate the maximum operating altitude conditions by overboosting (i.e., using a higher than normal power setting) at a lower altitude.

(2) It is the applicant's responsibility, in conjunction with the engine manufacturer, to define the test plan for the engine parameter evaluation up to the maximum approved takeoff altitude. Supportive data from the engine manufacturer on the same "type or series" of engine may also be included to reduce the amount of testing conducted.

(3) Extrapolation of engine performance data to 3,000 feet above the highest altitude tested (up to the maximum takeoff altitude to be approved) has been accepted, provided the supportive data, including the flight testing accomplished, establishes a consistent baseline.

(4) Detailed guidance for the testing necessary to show compliance with § 25.101(c) may be found in Advisory Circular 25-XX, "Turbojet Operations at High Altitude Airports," dated (to be released).

10. TAKEOFF AND TAKEOFF SPEEDS - §§ 25.105 AND 25.107 (PART 25 AS AMENDED THROUGH AMENDMENT 25-42).

a. Explanation, The primary objective of the takeoff tests required by § 25.107 is to determine the takeoff speed schedule for all takeoff configurations at all weight, altitude, and temperature conditions within the operational limits selected by the applicant. The provisions of § 25.105 are self-evident and are not repeated or amplified in this discussion. Guidance material for unpaved runway evaluation is contained in Chapter 8 (paragraph 234) of this Advisory Circular (AC).

b. Procedures. Although the following speed definitions are given in terms of calibrated airspeed, the Airplane Flight Manual (AFM) presentations shall be given in terms of indicated airspeed. Attention should be paid to all potential sources of airspeed error, but special consideration should be given to airplanes with electronic instruments in the cockpit that apply electronic filtering to the airspeed data. This filtering, which causes a time delay in the airspeed indication, can be a source of significant systematic error in the presentation of airspeed to the flightcrew. During a normal takeoff acceleration, the airplane will be at a higher speed than is indicated by the cockpit instrument, which can result in longer distances than are presented in the AFM, particularly in the event of a rejected takeoff near the indicated V_1 speed. The effects of any time delays caused by electronic filtering, pneumatic system lag, or other sources should be adequately addressed in the AFM speed and distance presentations. Further explanation of airspeed lag, particularly pertaining to airplanes with electronic instruments in the cockpit, and procedures for calibrating the airspeed indicating system (§ 25.1323(b)) are presented in paragraph 177 of this AC.

(1) Section 25.107(a)(1) - Engine Failure Speed (V_{EF}). The engine failure speed (V_{EF}) is defined as the calibrated airspeed at which the critical engine is assumed to fail and must be selected by the applicant. V_{EF} cannot be less than the ground minimum control speed (V_{MCG}) as described in §§ 25.149(e) and 25.107(a)(l).

* (2) Section 25.107(a)(2) - V_1. V_1 may not be less than V_{EF} plus the speed gained with the critical engine inoperative during the time interval between V_{EF} and the instant at which the pilot takes action after recognizing the engine failure (with the proviso that the time interval may not be less than one second). This action is indicated by pilot initiation of the first action to stop the airplane, such as brakes, throttles, spoilers, etc., during accelerate-stop tests, or by the first control input during V_{MCG} testing. The applicant may choose the sequence of pilot actions. Refer to paragraph 11 of this AC, addressing § 25.109, for a more complete description of rejected takeoff transition procedures and associated time delays. If it becomes evident in expanding the takeoff data for presentation in the AFM that excessive variation in V_1 exists due to the many performance variables involved (variations of ± 1.5 knots or + 100 ft. have been found acceptable), then measures must be taken to reduce the variability displayed in the AFM presentation. Examples of such measures are field length factors, or increments, and multiple web charts (accelerate-go/stop, V_1/V_R) for a particular configuration. *

(3) Section 25.107(b) - Minimum Takeoff Safety Speed (V_{2MIN}).

(i) V_{2MIN}, in terms of calibrated airspeed, cannot be less than:

(A) 1.1 times the V_{MCA} defined in § 25.149.

(B) 1.2 times V_S for two-engine and three-engine turbopropeller and reciprocating engine-powered airplanes and for all turbojet airplanes that do not have provisions for obtaining significant reduction in the one-engine inoperative power-on stalling speed (i.e., boundary layer control, blown flaps, etc.). The value of V_S to be used in determining V_{2-MIN} is the stall speed in the applicable takeoff configuration, landing gear retracted, except for those airplanes with a fixed landing gear or for gear-down dispatch.

(ii) V_{2MIN} may be reduced to 1.15 times V_S for turbopropeller and reciprocating engine-powered airplanes with more than three engines, and turbojet powered airplanes with adequate provisions for obtaining significant power-on stall speed reduction through the use of such things as boundary layer control, blown flaps, etc.

(iii) For propeller-driven airplanes, the difference between the two margins, based upon the number of engines installed on the airplane, is because the application of power ordinarily reduces the stalling speed appreciably. In the case of the two-engine propeller-driven airplane, at least half of this reduction is eliminated by the failure of an engine. The difference in the required factors therefore provides approximately the same margin over the actual stalling speed under the power-on conditions that are obtained after the loss of an engine, no matter what the number of engines (in excess of one) may be. Unlike the propeller-driven airplane, the turbojet/turbofan-powered airplane does not show any appreciable difference between the power-on and power-off stalling speed. This is due to the absence of the propeller, which ordinarily induces a slipstream with the application of power causing the wing to retain its lift to a speed lower than the power-off stalling speed. The applicant's selection of the two speeds specified will influence the nature of the testing required in establishing the takeoff flight path.

(4) <u>Section 25.107(c) - Takeoff Safety Speed</u> (V,). V_2 is the calibrated airspeed that is attained at or before the airplane reaches a height of 35 ft. above the takeoff surface after an engine failure at V_{EF} using an established rotation speed (V,). During the takeoff speeds demonstration, V_2 should be continued to an altitude sufficient to assure stable conditions beyond the 35-ft height. V_2 cannot be less than V_{2MIN}. In addition, V_2 cannot be less than the liftoff speed, V_{LOF}, as defined in § 25.107(f). In accordance with § 25.107(c), V_2 in terms of calibrated airspeed "...may not be less than V_R plus the speed increment attained before reaching a height of 35 feet above the takeoff surface." Section 25.11 l(c)(2) stipulates that the airplane must reach V_2 before it is 35 feet above the takeoff surface and continue at a speed nor less *than* V_2 until it is 400 feet above the takeoff surface. These requirements were first expressed in SR-422A, paragraphs 4T. 114(b)(4) and (c)(3) and 4T. 116(e). The intent of these requirements is discussed in the preamble to SR-422A, which states, in part, "For these reasons, this regulation permits the airplane to lift off the ground at a speed lower than the V_2 speed." The concern that the regulation change was addressing was the overshoot of V_2 after liftoff when it was required that the airplane attain V_2 on, or near, the ground. It was therefore the intent of the regulation to allow an acceleration to V_2 after liftoff but not to allow a decrease in the field length required to attain a height of 35 feet above the takeoff surface by attaining a speed greater than V_2, under low drag ground conditions, and using the excess kinetic energy to attain the 35 foot height.

(i) In the case of turbojet powered airplanes, when the bulk of the one-engine-inoperative data have been determined with idle cuts, V_2, and its relationship to V,, should be substantiated by a limited number of fuel cuts at V_{EF}. For derivative programs not involving a new or modified engine type (i.e., a modification that would affect thrust decay characteristics), fuel cuts arc unnecessary if thrust decay characteristics have been adequately substantiated.

(ii) For propeller-driven airplanes, the use of fuel cuts can be more important in order to ensure that the takeoff speeds and distances are obtained with the critical engine's propeller attaining the position it would during a sudden engine failure. The number of tests that should be conducted using fuel cuts, if any, depends on the correlation obtained with the idle cut data and substantiation that the data analysis methodology adequately models the effects of a sudden engine failure.

(5) <u>Section 25.107(d) - Minimum Unstick Speed (V_{MU})</u>.

(i) An applicant should comply with § 25.107(d) by conducting minimum unstick speed (V,,) determination tests with all engines operating and with one engine inoperative. If a stick pusher is installed, it should normally be active and set to the minimum angle of attack side of its rigging tolerance band. If desired, artificial stall warning systems may be disabled for this demonstration. (See paragraph (vi) below for further discussion regarding the setting of stick pusher and stall warning systems during V_{MU} testing.) During this demonstration, the takeoff should be continued until the airplane is out of ground effect. The airplane pitch attitude should not be decreased after liftoff.

(ii) In lieu of conducting actual one-engine-inoperative V_{MU} tests, the applicant may conduct all-engines-operating V_{MU} tests that simulate and account for all pertinent factors that would be associated with an actual one-engine-inoperative V_{MU} test. To account fully for pertinent factors, it may be necessary to adjust the resulting V_{MU} test values analytically. The factors to be accounted for must at least include the following:

(A) Thrust/weight ratio for the one-engine-inoperative range.

(B) Controllability (may be related to one-engine-inoperative free air tests, such as V,, V_{MCA}, etc.).

(C) Increased drag due to lateral/directional control systems.

(D) Reduced lift due to devices such as wing spoilers used for lateral control.

(E) Adverse effects of any other systems or devices on control, drag, or lift.

(iii) The number of V_{MU} tests required may be minimized by testing only the critical all-engines-operating and one-engine-inoperative thrust/weight ratios, provided that the V_{MU} speeds determined at these critical conditions are used for the range of thrust/weights appropriate to the all-engines-operating and one-engine-inoperative configurations. The critical thrust/weight is established by correcting, to the V_{MU} speed, the thrust that results in the airplane achieving its limiting one-engine-inoperative climb gradient at the normally scheduled speed and in the appropriate configuration.

(iv) Amendment 25-42, effective March 1, 1978, revised §§ 25.107(d) and 25.107(e)(1)(iv) in order to permit the one-engine-inoperative V_{MU} to be determined by all-engines-operating tests at the thrust/weight ratio corresponding to the one-engine-inoperative condition. As revised, § 25.107(d) specifies that V,,, must be selected for the range of thrust/weight ratios to be certificated, rather than for the all-engines-operating and one-engine-inoperative conditions as was previously required. In determining the all-engines-operating thrust/weight ratio that corresponds to the one-engine-inoperative condition, consideration should be given to trim and control drag differencc between the two configurations in addition to the effect of the number of engines operating. The minimum thrust/weight ratio to be certificated is established by correcting, to the V_{MU} speed, the thrust that results in the airplane achieving its limiting cnginc-out climb gradient in the appropriate configuration and at the normally scheduled speed.

(v) To conduct the V_{MU} tests, rotate the airplane as necessary to achieve the V,,, attitude. It is acceptable to use some additional nose-up trim over the normal trim setting during V_{MU} demonstrations. If additional nose-up trim is required, the additional considerations of paragraph (vii), below, apply. V,,, is the speed at which the weight of the airplane is completely supported by aerodynamic lift and thrust forces. Some judgment may be necessary on airplanes that have tilting main landing gear bogies. Determining the liftoff point from gear loads and wheel speeds has been found acceptable in past programs. After liftoff, the airplane should be flown out of ground effect. During liftoff and the subsequent climbout, the airplane should be fully controllable.

(vi) V_{MU} testing is a maximum performance flight test maneuver, and liftoff may occur very near thc angle of attack for maximum lift coefficient. Also, even though pitch attitude may be held fairly constant during the maneuver, environmental conditions and transiting through ground effect may result in consequential changes in angle of attack. It is permissible to lift off at a speed that is below the normal stall warning speed, provided no more than light buffet is encountered. An artificial stall warning system (e.g., a stick shaker) may be disabled during V_{MU} testing, although doing so will require cxtrcmc caution and depend upon a thorough knowledge of the airplane's stall characteristics. If the airplane is equipped with a stick pusher, for flight test safety reasons it should normally be active and set to the minimum angle of attack side of its rigging tolerance band. However, depending on the airplane's stall characteristics and the stick pusher design, disabling the pusher or delaying activation of the system until a safe altitude is reached may be the safer course. Again, this decision should be made only with a thorough knowledge of the airplane's stall characteristics combined with a complete understanding of the stick pusher design.

(vii) V_{MU} Testing for Airplanes Having Limited Pitch Control Authority.

(A) For some airplanes with limited pitch control authority, it may not be possible, at forward c.g. and normal trim, to rotate the airplane to a liftoff attitude where the airplane could otherwise perform a clean flyaway at a minimum speed had the required attitude been achieved. This may occur only over a portion of the takeoff weight range in some configurations. When limited pitch control authority is clearly shown to be the case, V,,, test conditions may be modified to allow testing aft of the forward c.g. limit and/or with use of more airplane nose-up trim than normal. The V_{MU} data determined with this procedure should be corrected to those values representative of the appropriate forward limit; the variation of V_{MU} with c.g. may be assumed to be like the variation of free air stalling speed with c.g. Although the development of scheduled takeoff speeds may proceed from these corrected V_{MU} data, additional tests are required (see paragraph (B) below) to check that the relaxed V_{MU} criteria have not neglected problems that might arise from operational variations in rotating airplanes with limited pitch control authority.

(B) In the following assurance test, the airplane must demonstrate safe flyaway characteristics.

(1) Minimum speed liftoff should be demonstrated at the critical forward c.g. limit with normal trim. For airplanes with a cutback forward c.g. at heavy weight, two weight/c.g. conditions should be considered. The heavy weight tests should be conducted at maximum structural or maximum sea level climb-limited weight with the associated forward c.g. The full forward c.g. tests should be conducted at the highest associated weight. These tests should be conducted at minimum thrust/weight for both the simulated one-engine-inoperative test (symmetrical reduced thrust) and the all-engines-operating case.

(2) One acceptable test technique is to hold full nose-up control column as the airplane accelerates. As pitch attitude is achieved to establish the minimum liftoff speed, pitch control may be adjusted to prevent overrotation, but the liftoff attitude should be maintained as the airplane flies off the ground and out of ground effect.

(3) Resulting liftoff speeds do not affect AFM speed schedules if the test proves successful and the resulting liftoff speed is at least 5 knots below the normally scheduled liftoff speed. Adjustments should be made to the scheduled V_R, forward c.g. limit, etc., if necessary, to achieve this result.

(4) This minimum 5-knot reduction below the scheduled liftoff speed provides some leeway for operational variations such as mis-trim, c.g. errors, etc. that could further limit the elevator authority. The reduced V_{MU} margins of the minimum liftoff speeds demonstrated in this test, relative to those specified in § 25.107(e)(1)(iv), result from the reduced probability of a pitch control authority-limited airplane getting into a high drag condition due to over-rotation.

(viii) V,,, Testing for Geometry Limited Airplanes.

(A) For airplanes that are geometry limited, the 110 percent of V,,, required by § 25.107(e)(1)(iv) may be reduced to an operationally acceptable value of 108 percent on the basis that equivalent airworthiness is provided for the geometry-limited airplane. For acceptance of the 108 percent of V,,, liftoff speed, safeguards protecting the geometry-limited airplane against both over-rotation on the ground and in the air must be provided. Also, the airplane should be geometry limited to the extent that a maximum gross weight takeoff with the tail dragging will result in a clean liftoff and fly-away in the all-engines-operating condition. During such a takeoff for the all-engines-operating condition, the resulting distance to the 35 ft. height must not be greater than 105 percent of the normal takeoff distance under similar weight, altitude, and temperature conditions before the 15 percent margin is added. Lastly, the V_{MU} demonstrated must be sound and repeatable. Compliance with these criteria should be formally addressed in a finding of equivalent safety.

(B) The criteria for demonstrating the capability for a clean liftoff and fly-away are as follows:

(1) The airplane's pitch attitude from a speed of 96 percent of the actual liftoff speed must be within 5 percent (in degrees) of the tail-dragging attitude to the point of liftoff.

(2) During the above speed range (96 to 100 percent of the actual liftoff speed), the aft under-surface of the airplane must have achieved actual runway contact. It has been found acceptable in tests for contact to exist approximately 50 percent of the time that the airplane is in this speed range.

(3) Beyond the point of liftoff to a height of 35 ft., the airplane's pitch attitude must not decrease below that at the point of liftoff, or the speed must not increase more than 10 percent.

(4) The airplane shall be at the critical thrust/weight condition, as defined in § 25.107(d), but with all engines operating.

(ix) V_{MU} for a Stretched Version of a Tested Airplane.

(A) It has been considered that the V_{MU} speed represents the aerodynamic potential minimum liftoff speed related to a safe liftoff and fly-away, even though the body contact attitude may prevent achieving the lift coefficient (C_L) for this speed. Such is the case when V_{MU} is determined with body contact, whether or not geometry-limited "credit" is sought, It is therefore concluded that a V,,, schedule obtained on one model of an airplane type may be applied to a geometry-limited stretched version of that tested airplane. The 108 percent speed factor of paragraph 10b(5)(viii)(A), above, is only applicable to the stretched version if it was applicable to the tested airplane.

(B) Since the concern for tail strikes is increased with the stretched airplane, the following shall be accomplished, in addition to normal takeoff tests, when applying a shorter body airplane's V_{MU}, schedule to the stretched derivative:

(1) Scheduled rotation speeds (V,) for the stretched airplane should result in at least the required liftoff speed margins above V,,, (i.e., 1.05 and 1.10 or 1.08, as applicable) of the shorter body airplane, corrected for the reduced runway pitch attitude capability and revised c.g. range of the stretched airplane.

(2) At both the forward and aft c.g. limits, and over the thrust-to-weight range for each takeoff flap, the following abuse takeoff tests must be accomplished, The tests described in paragraphs (i) and (ii), below, should be accomplished with not more than occasional, minor (i.e., non-damaging) tail strikes.

(i) All-engines-operating, early rotation abuse tests specified in paragraph 10b(6)(iii)(B), including both the rapid rotations and over-rotations as separate test conditions.

(ii) One-engine-inoperative, early rotation abuse tests specified in paragraph I 0b(6)(ii).

(iii) All-engines-operating, moderate rotation rate (i.e., more rapid than normal) takeoff abuse tests, using the scheduled V_R, and normal pitch attitude after liftoff. No tail strikes may occur for this condition.

(6) Section 25.107(e) - Rotation Speed (V_R).

(i) The rotation speed, (V,) in terms of calibrated airspeed, must be selected by the applicant. V_R has a number of constraints that must be observed in order to comply with § 25.107(e):

(A) V_R may not be less than V,; however, it can be equal to V, in some cases.

(B) V_R may not be less than 105 percent of the air minimum control speed (V_{MCA}).

(C) V_R must be a speed that will allow the airplane to reach V_2 at or before reaching a height of 35 ft. above the takeoff surface.

(D) V_R must be a speed that will result in liftoff at a speed not less than 110 percent of V_{MU} (unless geometry limited) for the all-engines-operating condition and not less than 105 percent of the V,,, determined at the thrust/weight ratio corresponding to the one-engine-inoperative condition for each set of conditions such as weight, altitude, temperature, and configuration when the airplane is rotated at its maximum practicable rate.

(ii) Early rotation, one-engine-inoperative abuse test.

(A) In showing compliance with § 25.107(e)(3), some guidance relative to the airspeed attained at the 35-ft. height during the associated flight test is necessary. As this requirement dealing with a rotation speed abuse test only specifies an early rotation (V_R-5 knots), it is interpreted that pilot technique is to remain the same as normally used for a one-engine-inoperative condition. With these considerations in mind, it is apparent that the airspeed achieved at the 35-ft. point can be somewhat below the normal scheduled V_2 speed. However, the amount of permissible V_2 speed reduction must be limited to a reasonable amount as described below.

(B) These test criteria are applicable to all unapproved, new, basic model airplanes. They are also applicable to previously approved airplanes when subsequent abuse testing is warranted. However, for those airplanes where the criteria herein are more stringent than that previously applied, consideration will be given to permitting some latitude in the test criteria.

(C) In conducting the flight tests required by § 25.107(e)(3), the test pilot shall use a normal/natural rotation technique as associated with the use of scheduled takeoff speeds for the airplane being tested. Intentional tail or tailskid contact is not considered acceptable. Further, the airspeed attained at the 35-R. height during this test must not be less than the scheduled V_2 value minus 5 knots. These speed limits should not be considered or used as target V_2 test speeds, but rather are intended to provide an acceptable range of speed departure below the scheduled V_2 value.

(D) In this abuse test, the simulated engine failure should be accomplished sufficiently in advance of the V_R test speed to allow for engine spin-down, unless this would be below the V_{MCG}, in which case V_{MCG} should govern. The normal one-engine-inoperative takeoff distance may be analytically adjusted to compensate for the effect of the early thrust reduction. Further, in those tests where the airspeed achieved at the 35-a. height is slightly less than the V_2-5 knots limiting value, it will be permissible, in lieu of conducting the tests again, to analytically adjust the test distance to account for the excessive speed decrement.

(iii) All-engines-operating abuse tests.

(A) Section 25.107(e)(4) states that there must not be a “marked increase” in the scheduled takeoff distance when reasonably expected service variations such as early and excessive rotation and out-of-trim conditions are encountered. This has been interpreted as requiring takeoff tests with all engines operating with:

(1) An abuse on rotation speed, and

(2) Out-of-trim conditions, but with rotation at the scheduled V_R speed.

NOTE: The expression “marked increase” in the takeoff distance is defined as any amount in excess of 1 percent of the scheduled takeoff distance. Thus, the abuse tests should not result in field lengths more than 10 1 percent of the takeoff field lengths calculated in accordance with the applicable requirements of Part 25 for presentation in the AFM.

(B) For the early rotation abuse condition with all engines operating, and at a weight as near as practicable to the maximum sea level standard day takeoff weight limit, it should be shown by test that when the airplane is overrotated at a speed below the scheduled V,, no “marked increase” in the scheduled AFM field length will result. For this demonstration, the airplane should be rotated at a speed 7 percent or 10 knots, whichever is less, below the scheduled V_R Tests should be conducted at a rapid rotation rate or should include an over-rotation of 2 degrees above normal attitude after liftoff. Tail strikes during this demonstration are acceptable if they are minor and do not result in unsafe conditions.

(C) For reasonably expected out-of-trim conditions with all engines operating and as near as practicable to the maximum weight allowed under sea level standard day conditions, it should be shown that there will not be a “marked increase” in the scheduled AFM takeoff distance when rotation is initiated in a normal manner at the scheduled V_R speed, (See paragraph 2 1 (c)(7)(ii) for additional guidance regarding the evaluation of flight characteristics for out-of-trim conditions.) The amount of mistrim should be the maximum mistrim that would not result in a takeoff configuration warning, including taking into account the takeoff configuration warning system-rigging tolerance. It is permissible to accept an analysis in lieu of actual testing if the analysis shows that the out-of-trim condition would not present unsafe flight characteristics or “marked increase” in the scheduled AFM field lengths.

(iv) Stall Warning During Takeoff Speed Abuse Tests. The presumption is that if an operational pilot was to make an error in takeoff speeds that resulted in an encounter with stall warning, the likely response would be to aggressively recover to a safe flight condition rather than making a conscious effort to duplicate the AFM takeoff performance data. Therefore, the activation of any stall warning devices, or the occurrence of airframe buffeting during takeoff speed abuse testing, is unacceptable.

(7) Section 25.107(f) - Liftoff Speed (V_{LOF}). The liftoff speed (V_{LOF}) is defined as the calibrated airspeed at which the airplane first becomes airborne (i.e., no contact with the runway). This allows comparison of liftoff speed with tire limit speed. V_{LOF} differs from V_{MU} in that V,,, is the minimum possible V_{LOF} speed for a given configuration, and depending upon landing gear design, V,,, liftoff is shown to be the point where all of the airplane weight is being supported by airplane lift and thrust forces and not any portion by the landing gear. For example, after the V_{MU} speed is reached, a truck tilt actuator may force a front or rear wheel set to be in contact with the runway, even though the flyoff is in progress by virtue of lift being greater than weight.

* 11. ACCELERATE-STOP DISTANCE - § 25.109.

a. Explanation. This section describes test demonstrations and data expansion methods necessary to determine accelerate-stop distances for publication in the FAA-approved Airplane Flight Manual (AFM), as required by § 25.1583(h) (by reference to § 25.1533). Amendment 25-92 revised some aspects of the Part 25 accelerate-stop criteria and added new requirements related to the stopping capability of the airplane as affected by brake wear and wet runways. The changes imparted to the accelerate-stop requirements by Amendment 25-92 are listed below. (For other material related to the use of accelerate-stop distances, see Parts 12 1 and 135 of the FAR.) *

(1) Section 25.101(i) was added to require accelerate-stop distances to be determined with all the airplane wheel brake assemblies at the fully worn limit of their allowable wear range.

(2) Section 25.105(c)(1) was revised to require takeoff data to be determined for wet, in addition to dry, hard surfaced runways. At the applicant's option, takeoff data may also be determined for wet runways that have grooved or porous friction course surfaces.

(3) Section 25.107(a)(2) was revised to remove the reference to "takeoff decision speed" from the definition of V,.

(4) Section 25.109 was revised to add a requirement to determine accelerate-stop distances for wet runways. Additionally, the requirement for the AFM expansion to include two seconds of continued acceleration beyond V,, with the operating engines at takeoff thrust, as introduced by Amendment 25-42, was replaced with a distance increment equivalent to two seconds at V,. Also, the text of § 25.109(a) was modified to clarify that the accelerate-stop distances must take into account the highest speed reached during the rejected takeoff maneuver, including, as applicable, speeds higher than V_1.

(5) Section 25.109(f) was added to permit credit for the use of reverse thrust in determining wet runway accelerate-stop distances (subject to the requirements of § 25.109(e)) and to explicitly deny reverse thrust credit for determining dry runway accelerate-stop distances.

(6) Section 25.109(i) was added to require a maximum brake energy accelerate-stop test to be conducted with not more than 10 percent of the allowable brake wear range remaining on each individual wheel-brake assembly.

(7) Section 25.735(h) was added to require the maximum rejected takeoff brake energy absorption capacity rating used during qualification testing to the applicable Technical Standard Order to be based on the fully worn limit of the brake's allowable wear range.

(8) Section 25.1533(a)(3) was revised to add runway surface condition (dry or wet) as a variable that must be accounted for in establishing minimum takeoff distances. Section 25.1533(a)(3) was also revised to allow wet runway takeoff distances on grooved and porous friction course (PFC) runways to be established as additional operating limitations, but approval to use these distances is limited to runways that have been designed, constructed, and maintained in a manner acceptable to the FAA Administrator.

b. The applicable Federal Aviation Regulations (FAR) are § 25.109, and the following:

§ 25.101(f)	Airplane configuration and procedures.
§ 25.101(h)	Pilot retarding means time delay allowances.
§ 25.101(i)	Worn brake stopping performance.

§ 25.105	Takeoff configuration and environmental and runway conditions.
§§ 25.107(a)(l) & (2)	Defines V, and V_{EF} speeds.
§ 25.735	Brakes.
§ 25.1301	Function and installation.
§ 25.1309	Equipment, systems, and installation.
§ 25.1533	Additional operating limitations - maximum takeoff weights and minimum takeoff distances.
§ 25.1583(h)	FAA-approved Airplane Flight Manual - operating limitations.
§ 25.1587	FAA-approved Airplane Flight Manual - performance information.

c. Procedures. The following paragraphs provide guidance for accomplishing accelerate-stop flight tests and expanding the resulting data for the determination of AFM performance information.

(1) Accelerate-stop testing. The following guidance is applicable to turbine-powered airplanes with and without propellers. Guidance regarding flight testing applies only to dry runway accelerate-stop distances, Guidance for expanding the flight test data to determine AFM distances applies to both dry and wet runways, unless otherwise noted. Further guidance for determining wet runway accelerate-stop distances is provided in paragraph 11 c(4).

(i) In order to establish a distance that would be representative of the distance needed in the event of a rejected takeoff, where the first action to stop the airplane is taken at or below V,, a sufficient number of test runs should be conducted for each airplane configuration specified by the applicant, (For intermediate configurations, see paragraph 3 of this advisory circular.)

(ii) The guidance outlined in paragraph 1 lc(3) describes how to apply the appropriate time delays, as required by § 25.101(h)(3), for the flightcrew to accomplish the rejected takeoff operating procedures.

(iii) Section 25.101(i) states that the accelerate-stop distances must be determined with all the airplane wheel-brake assemblies at the fully worn limit of their allowable wear range. The fully worn limit is defined as the amount of wear allowed before the brake must be removed from the airplane for overhaul. The allowable wear should be defined in terms of a linear dimension in the axial direction, which is typically determined by measuring the wear pin extension.

(A) The only accelerate-stop test that must be conducted at a specific brake wear state is the maximum brake kinetic energy demonstration, which must use brakes that have no more than 10 percent of the allowable brake wear range remaining (see paragraph 11 c(2)(iii)). The remainder of the accelerate-stop tests may be conducted with the brakes in any wear state as long as a suitable combination of airplane and dynamometer tests is used to determine the accelerate-stop distances corresponding to fully worn brakes. For example, dynamometer testing may be used to determine whether there is a reduction in brake performance from the wear state used in the airplane tests to a fully worn brake. The airplane test data could then be adjusted analytically for this difference without additional airplane testing.

(B) Either airplane-worn or mechanically-worn brakes (i.e., machined or dynamometer worn) may be used. If mechanically-worn brakes are used, it must be shown that they can be expected to provide similar results to airplane-worn brakes. This comparison can be based on service experience on the test brake or an appropriate equivalent brake, or on dynamometer wear test data when service data are unavailable.

(iv) Section 25.109(f)(1) denies credit for the use of reverse thrust as a decelerating means in determining the accelerate-stop distance for a dry runway. This provision applies to both turbine engine and propeller engine reverse thrust. Credit for the additional deceleration available from reverse thrust is permitted for wet runway accelerate-stop distances, provided the thrust reverser system is shown to be safe, reliable, capable of giving repeatable results, and does not require exceptional skill to control the airplane. (See paragraph 1 lc(4)(v) for guidance related to obtaining accelerate-stop performance credit for reverse thrust on wet runways.)

(v) The accelerate-stop test runs should be conducted at weight/speed combinations that will provide an even distribution of test conditions over the range of weights, speeds, and brake energies for which takeoff data will be provided in the AFM. The effects of different airport elevations can be simulated at one airport elevation, provided the braking speeds employed are relevant for the range of airplane energies that must be absorbed by the brakes. The limiting brake energy value in the AFM shall not exceed the maximum demonstrated in these tests or the maximum for which the brake has been approved. (See paragraph 1 lc(2) for further guidance related to tests and analyses for the demonstration of the maximum brake energy absorption capability.)

(vi) The V, speeds used in the accelerate-stop tests need not correspond precisely to the AFM values for the test conditions since it may be necessary to increase or decrease the AFM V, speed to fully investigate the energy range and weight envelope.

(vii) A total of at least six accelerate-stop flight tests should be conducted. Unless sufficient data are available for the specific airplane type showing how braking performance varies with weight, kinetic energy, lift, drag, ground speed, torque limit, etc., at least two tests should be conducted for each configuration when the same braking coefficient of friction is being claimed for multiple aerodynamic configurations. These tests must be conducted on hard surfaced, dry runways.

(viii) For approval of dispatch capability with anti-skid inoperative, nose wheel brakes or specified main wheel-brake(s) inoperative, autobraking systems, etc., a full set of tests, as in paragraph (vii) above, should normally be conducted. A lesser number of tests may be accepted for "equal or better" demonstrations, to establish small increments or if adequate conservatism is used during testing.

(ix) Either ground or airborne instrumentation should include means to determine the horizontal distance time-history.

(x) The wind speed and direction relative to the test runway should be determined and corrected to a height corresponding to the approximate height of the mean aerodynamic chord. (See paragraph 3 of this advisory circular.)

(xi) The accelerate-stop tests should be conducted in the following configurations:

(A) Heavy to light weight as required.

(B) Most critical c.g. position.

(C) Wing flaps in the takeoff position(s).

(D) Tire pressure: before taxi and with cold tires, set to the highest value appropriate to the takeoff weight for which approval is being sought.

(E) Engine idle thrust: set at the recommended upper limit for use on the ground or the effect of maximum ground idle thrust may be accounted for in data analyses. For maximum brake energy and fuse plug no-melt tests, data analysis may not be used in place of maximum ground idle thrust.

(xii) Engine thrust should be appropriate to each segment of the rejected takeoff and should include accounting for thrust decay rates (i.e., spindown) for failed or throttled back engines. At the speed that corresponds to the energy level defined for the test demonstration, the stopping sequence is initiated by employing the first acceptable braking means.

(A) Turbojet powered airplanes. For AFM calculation purposes, the critical engine failure accelerate-stop data may be based on the failed engine spinning down to a windmilling condition. (Note: If, due to the certification basis of the airplane, all-engine-accelerate-stop distances are not being considered, the one-engine-inoperative AFM distances should be based on the critical engine failing to maximum ground idle thrust rather than the windmilling condition.) The thrust from the operative engine(s) should be consistent with a throttle chop to maximum ground idle thrust. For determining the all-engines-operating dry runway accelerate-stop AFM distances, the stopping portion should be based on all engines producing maximum ground idle thrust (after engine spindown), as noted in paragraph 1 lc(1)(xi)(E). The accelerate-stop tests may be conducted with either concurrent or sequential throttle chops to idle thrust as long as the data are adjusted to take into account pilot reaction time, and any control, system, or braking differences (e.g., electrical or hydraulic/mechanical transients associated with an engine failing to a windmilling condition resulting in reduced braking effectiveness). Test data should also be analytically corrected for any differences between maximum ground idle thrust and the idle thrust level achieved during the test. For the criteria relating to reverse thrust credit for wet runway accelerate-stop distances, see paragraph 11 c(4)(v).

(B) Turbopropeller-powered airplanes. For the one-engine-inoperative accelerate-stop distances, the critical engine's propeller should be in the position it would normally assume when an engine fails and the power levers are closed. For dry runway one-engine-inoperative accelerate-stop distances, the high drag ground-idle position of the operating engines' propellers (defined by a pitch setting that results in not less than zero total thrust, i.e., propeller plus jet thrust, at zero airspeed) may be used provided adequate directional control is available on a wet runway and the related operational procedures comply with §§ 25.109(f) and (h). Wet runway controllability may either be demonstrated by using the guidance available in paragraph 11 c(4)(v)(F) at the appropriate power level, or adequate control can be assumed to be available at ground idle power if reverse thrust credit is approved for determining the wet runway accelerate-stop distances. For the all-engines-operating accelerate-stop distances on a dry runway, the high drag ground-idle propeller position may be used for all engines (subject to § 25.109(f) and (h)). For the criteria relating to reverse thrust credit for wet runway accelerate-stop distances, see paragraph 1 lc(4)(v).

(xiii) System transient effects (e.g., engine spin-down, brake pressure ramp-up, etc.) should be determined and properly accounted for in the calculation of AFM accelerate-stop distances (see paragraph 1 lc(3)(ix)).

(2) Maximum Brake Energy Testing. The following paragraphs describe regulatory requirements and acceptable test methods for conducting an accelerate-stop test run to demonstrate the maximum energy absorption capability of the wheel-brakes.

(i) The maximum brake energy accelerate-stop demonstration should be conducted at not less than the maximum takeoff weight and should be preceded by at least a 3-mile taxi with all engines operating at maximum ground idle thrust, including three full stops using normal braking. Following the maximum brake energy stop, it will not be necessary to demonstrate the airplane's ability to taxi.

(ii) Section 25.735(h) requires the rejected takeoff brake kinetic energy capacity rating of each main wheel-brake assembly to be determined at the fully worn limit of its allowable wear range. The calculation of maximum brake energy limited takeoff weights and speeds, for presentation in the AFM performance section, must therefore be based on each airplane main wheel-brake being in the fully worn condition.

(iii) Section 25.109(i) requires a flight test demonstration of the maximum brake kinetic energy accelerate-stop distance to be conducted with not more than 10 percent of the allowable brake wear range remaining on each of the airplane wheel-brakes. The 10 percent allowance on the brake wear state is intended to ease test logistics and increase test safety, not to allow the accelerate-stop distance to be determined with less than fully worn brakes. If the brakes are not in the fully worn state at the beginning of the test, the accelerate-stop distance should be corrected as necessary to represent the stopping capability of fully worn brakes.

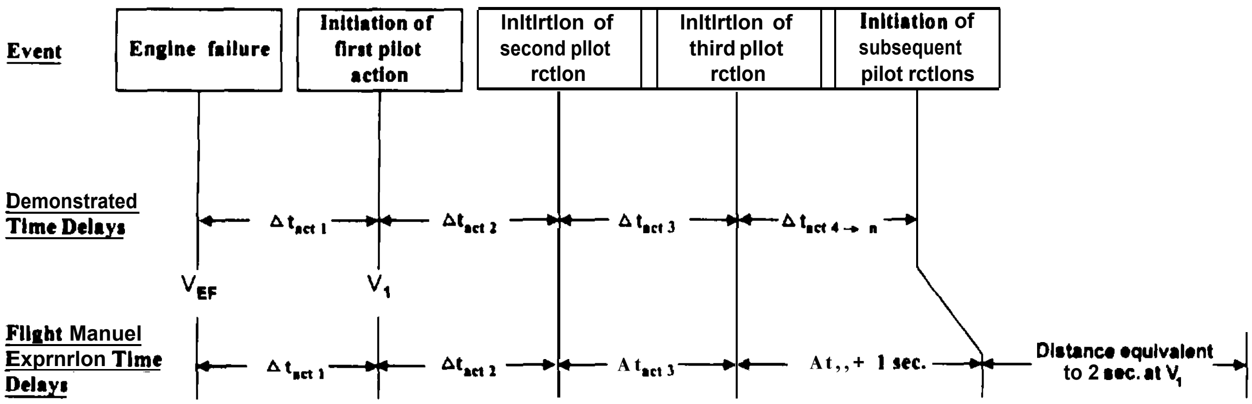
(iv) The maximum airplane brake energy allowed for dispatch should not exceed the value for which a satisfactory after-stop condition exists, or the value documented under the applicable Technical Standard Order (TSO) (or an acceptable equivalent), whichever value is less. A satisfactory after-stop condition is defined as one in which tires are confined to tires, wheels, and brakes, such that progressive engulfment of the rest of the airplane would not occur during the time of passenger and crew evacuation. The application of fire fighting means or artificial coolants should not be required for a period of 5 minutes following the stop.

(v) Landings are not an acceptable means for demonstrating the maximum rejected takeoff brake energy. Though permitted in the past, service experience has shown that methods used to predict brake and tire temperature increases that would have occurred during taxi and acceleration, as specified in paragraph 1 l(c)(2)(i), were not able to accurately account for the associated energy increments.

(3) Accelerate-Stop Time Delays. Section 25.101(h) of the FAR requires allowance for time delays in the execution of procedures. Amendment 25-42 (effective March 1, 1978) amended the airworthiness standards to clarify and standardize the method of applying these time delays to the accelerate-stop transition period. Amendment 25-42 also added the critical engine failure speed, V_{EF}, and clarified the meaning of V, with relation to V,,. The preamble to Amendment 25-42 states that "V, is determined by adding to V_{EF} (the speed at which the critical engine is assumed to fail) the speed gained with the critical engine inoperative during the time interval between the instant at which the critical engine is failed and the instant at which the test pilot recognizes and reacts to the engine failure, as indicated by the pilot's application of the first retarding means during accelerate-stop tests." Thus it can be seen that V, is not only intended to be at the end of the decision process, but it also includes the time it takes for the pilot to perform the first action to stop the airplane. The purpose of the time delays is to allow sufficient time (and distance) for a pilot, in actual operations, to accomplish the procedures for stopping the airplane. The time delays are not intended to allow extra time for making a decision to stop as the airplane passes through V,. Since the typical transport category airplane requires three pilot actions (i.e., brakes-throttles-spoilers) to achieve the final braking configuration, Amendment 25-42 defined a two-second time period, in § 25.109, to account for delays in activating the second and third deceleration devices. Amendment 25-92 (effective March 20, 1998) redefined, and reinterpreted the application of that two-second delay time as a distance increment equivalent to two seconds at V,. No credit may be taken for system transient effects (e.g., engine spin-down, brake pressure ramp-up, etc.) in determining this distance. The following paragraphs provide guidance related to the interpretation and application of delay times to show compliance with the accelerate-stop requirements of Amendment 25-92.

(i) Figure 1 1-1 presents a pictorial representation of the accelerate-stop time delays considered acceptable for compliance with § 25.10 1 (h) as discussed above.

FIGURE 1 1 - 1. ACCELERATE-STOP TIME DELAYS



(ii) V_{EF} is the calibrated airspeed selected by the applicant at which the critical engine is assumed to fail. The relationship between V_{EF} and V_1 is defined in § 25.107.

(iii) Δt_{act} , = the demonstrated time interval between engine failure and initiation of the first pilot action to stop the airplane. This time interval is defined as beginning at the instant the critical engine is failed and ending when the pilot recognizes and reacts to the engine failure, as indicated by the pilot's application of the first retarding means during accelerate-stop tests. A sufficient number of demonstrations should be conducted using both applicant and FAA test pilots to assure that the time increment is representative and repeatable. The pilot's feet should be on the rudder pedals, not the brakes, during the tests. For AFM data expansion purposes, in order to provide a recognition time increment that can be executed consistently in service, this time increment must be equal to the demonstrated time or one second, whichever is greater. If the airplane incorporates an engine failure warning light, the recognition time includes the time increment necessary for the engine to spool down to the point of warning light activation, plus the time increment from light "on" to pilot action indicating recognition of the engine failure.

(iv) $\Delta t_{act\ 2}$ = the demonstrated time interval between initiation of the first and second pilot actions to stop the airplane.

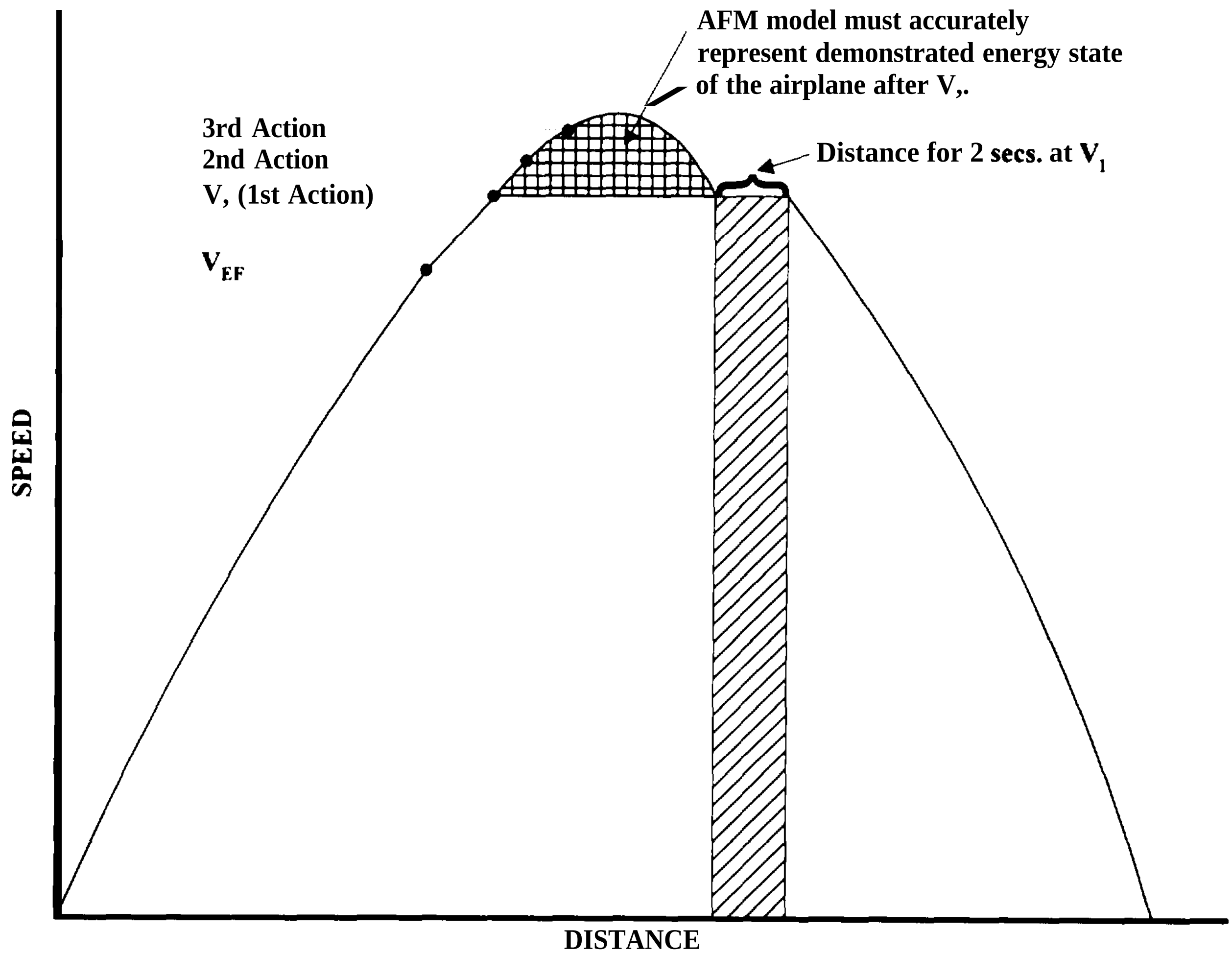
(v) Δt_{act} 3 = the demonstrated time interval between initiation of the second and third pilot actions to stop the airplane.

(vi) $\Delta t_{act\ 4 \rightarrow n}$ = the demonstrated time interval between initiation of the third and fourth (and any subsequent) pilot actions to stop the airplane. For AFM expansion, a one-second reaction time delay to account for in-service variations should be added to the demonstrated time interval between the third and fourth (and any subsequent) pilot actions. If a command is required for another crewmember to initiate an action to stop the airplane, a two-second delay, in lieu of the one-second delay, should be applied for each action. For automatic deceleration devices that are approved for performance credit for AFM data expansion, established systems actuation times determined during certification testing may be used without the application of the additional time delays required by this paragraph.

(vii) The sequence for initiation of pilot actions may be selected by the applicant, but it must match the sequence established for operation in service, as prescribed by § 25.101(f). If, on occasion, the specified sequence is not achieved during testing, the test need not be repeated; however, sufficient testing must be conducted to establish acceptable values of At,,,.

(viii) Sections 25.109(a)(1)(iv) and (a)(2)(iii) require the one-engine-inoperative and all-engines-operating accelerate-stop distances, respectively, to include a distance increment equivalent to two seconds at V,. (Although the requirement for the distance increment equivalent to two seconds at V, is explicitly stated in the "dry runway" criteria of § 25.109, it is also applied to the "wet runway" accelerate-stop distances by reference in § 25.109(b).) This distance increment is represented pictorially on the right side of the "Flight Manual Expansion Time Delays" presentation in Figure l l-l, and in the speed versus distance plot of Figure l l-2, below. The two-second time period is only provided as a method to calculate the required distance increment, and is not considered to be a part of the accelerate-stop braking transition sequence. Consequently, no credit for pilot actions, or engine and systems transient responses (e.g., engine spin-down) may be taken during this two-second time period. Similarly, the two-second time period may not be reduced for airplanes incorporating automated systems that decrease the number of pilot actions required to obtain the full braking configuration (e.g., autospoiler systems).

FIGURE 1 l-2. ACCELERATE-STOP SPEED VS. DISTANCE



(ix) Any residual acceleration that occurs after V,, while the airplane and its systems become stabilized in the braking configuration, must be accounted for in the expansion of accelerate-stop performance data for presentation in the AFM. The effects of system transients, such as engine spin-down, brake pressure ramp-up, spoiler actuation times, etc., should be accounted for in this time period. The area of interest is noted at the top of the graphical representation of the speed versus distance relationship in Figure 11-2.

(x) All-Engine Accelerate-Stop Distance. For the all-engines-operating accelerate-stop distance prescribed by § 25.109(a)(2), apply the demonstrated time intervals, and associated delays, of paragraphs 1 lc(3)(iv) through (vi) after the airplane has accelerated to V,.

(xi) The procedures used to determine the accelerate-stop distance must be described in the performance section of the AFM.

(4) Wet Runway Accelerate-Stop Distance. The following guidance is provided for showing compliance with the requirements stated in §§ 25.109(b) through (d) for determining accelerate-stop distances applicable to wet runways. In general, the wet runway accelerate-stop distance is determined in a similar manner to the dry runway accelerate-stop distance. The only differences are in reflecting the reduced stopping force available from the wheel brakes on the wet surface and in provisions for performance credit for the use of reverse thrust as an additional decelerating means. The general method for determining the reduced stopping capability of the wheel brakes on a smooth wet runway is as follows: First, determine the maximum tire-to-ground wet runway braking coefficient of friction versus ground speed from the relationships provided in § 25.109(c)(1). Then, adjust this braking coefficient to take into account the efficiency of the anti-skid system. (See paragraph 1 1c(4)(ii) for a definition of anti-skid efficiency.) Next, determine the resulting braking force and adjust this force for the effect of the distribution of the normal load between braked and unbraked wheels at the most adverse center-of-gravity position approved for takeoff, as prescribed by § 25.109(b)(2)(ii). In accordance with § 25.109(b)(2)(i), apply further adjustments, if necessary, to ensure that the resulting stopping force attributed to the wheel brakes on a wet runway never exceeds (i.e., during the entire stop) the wheel brakes stopping force used to determine the dry runway accelerate-stop distance (under § 25.109(a)). Neither the dry runway brake torque limit nor the dry runway friction (i.e., anti-skid) limit should be exceeded. Alternative methods of determining the wet runway wheel brakes stopping force may be acceptable as long as that force does not exceed the force determined using the method just described.

(i) Maximum Tire-to-Ground Braking Coefficient of Friction. The values specified in § 25.109(c)(1) were derived from data contained in Engineering Sciences Data Unit (ESDU) 7 1026, "Frictional and Retarding Forces on Aircraft Types - Part II: Estimation of Braking Force," (August 198 1). The data in ESDU 7 1026 is a compilation from many different sources, including the National Aeronautics and Space Administration, the British Ministry of Aviation, and others. ESDU 7 1026 contains curves of wet runway braking coefficients versus speed for smooth and treaded tires at varying inflation pressures. These data are presented for runways of various surface roughness, including grooved and porous friction course runways. Included in the data presentation are bands about each of the curves, which represent variations in: water depths from damp to flooded, runway surface texture within the defined texture levels, tire characteristics, and experimental methods. In defining the standard curves of wet runway braking coefficient versus speed that are prescribed by the equations in § 25.109(c)(1), the effects of the following variables were considered: tire pressure, tire tread depth, runway surface texture, and the depth of the water on the runway.

(A) Tire Pressure: Lower tire pressures tend to improve the airplane's stopping capability on a wet runway. The effect of tire pressure is taken into account by providing separate curves (equations) in § 25.109(c)(1) for several tire pressures. As stated in the rule, the tire pressure used to determine the maximum tire-to-ground braking coefficient of friction must be the maximum tire pressure approved for operation. Linear interpolation may be used for tire pressures other than those listed.

(B) Tire Tread Depth: The degree to which water can be channeled out from under the tires significantly affects wet runway stopping capability. The standard curves of braking coefficient versus speed prescribed in § 25.109(c)(1) are based on a tire tread depth of 2 mm. This tread depth is consistent with tire removal and retread practices reported by airplane and tire manufacturers and tire retreaders. It is also consistent with FAA guidance provided in AC 121.195(d)- 1 A, regarding the tread depth for tires used in flight tests to determine operational landing distances on wet runways. Although operation with zero tread depth is not prohibited, it is unlikely that all of the tires on an airplane would be worn to the same extent.

(C) Runway Surface Texture: ESDU 71026 groups runways into five categories. These categories are labeled "A" through "E," with "A" being the smoothest and "C" the most heavily textured ungrooved runways. Categories "D" and "E" represent grooved and other open textured surfaces. Category A represents a very smooth texture (an average texture depth of less than 0.004 inches), and is not very prevalent in runways used by transport category airplanes. The majority of ungrooved runways fall into the category C grouping. The curves represented in § 25.109(c)(1) represent a texture midway between categories B and C.

(D) Depth of Water on the Runway: Obviously, the greater the water depth, the greater the degradation in braking capability. The curves prescribed in § 25.109(c)(1) represent a well-soaked runway, but with no significant areas of standing water.

(ii) Anti-Skid System Efficiency. Section 25.109(c)(2) requires adjusting the maximum tire-to-ground braking coefficient determined in § 25.109(c)(1) to take into account the efficiency of the anti-skid system. The anti-skid system efficiency is defined as the relative capability of the anti-skid system to obtain the maximum friction available between the tire and the runway surface (μ_{max}). It is expressed as either a percentage of μ_{max} or a factor based on that percentage (e.g., 85% or 0.85). Applicants can either use one of the anti-skid efficiency values specified in § 25.109(c)(2), or derive the efficiency from flight tests on a wet runway. Regardless of which method is used, § 25.109(c)(2) requires that an appropriate level of flight testing must be performed to verify that the anti-skid system operates in a manner consistent with the efficiency value used, and that the system has been properly tuned for operation on wet runways.

(A) Classification of Types of Anti-Skid Systems.

(1) The efficiency values specified in § 25.109(c)(2) are a function of the type of anti-skid systeminstalled on the airplane. Three broad system types are identified in the rule: on/off, quasi-modulating, and fully modulating. These classifications represent evolving levels of technology and differing performance capabilities on dry and wet runways. The classification of anti-skid system types and the assigned efficiency values are based on information contained in Society of Automotive Engineers (SAE) Aerospace Information Report (AIR) 1739, titled "Information on Anti-Skid Systems."

(2) On/off systems are the simplest of the three types of anti-skid systems. For these systems, full-metered brake pressure (as commanded by the pilot) is

applied until wheel locking is sensed. Brake pressure is then released to allow the wheel to spin back up. When the system senses that the wheel is accelerating back to synchronous speed (i.e., ground speed), full-metered pressure is again applied. The cycle of full pressure application/complete pressure release is repeated throughout the stop (or until the wheel ceases to skid with pressure applied).

(3) Quasi-modulating systems attempt to continuously regulate brake pressure as a function of wheel speed. Typically, brake pressure is released when the wheel deceleration rate exceeds a preselected value. Brake pressure is re-applied at a lower level after a length of time appropriate to the depth of the skid. Brake pressure is then gradually increased until another incipient skid condition is sensed. In general, the corrective actions taken by these systems to exit the skid condition are based on a pre-programmed sequence rather than the wheel speed time history.

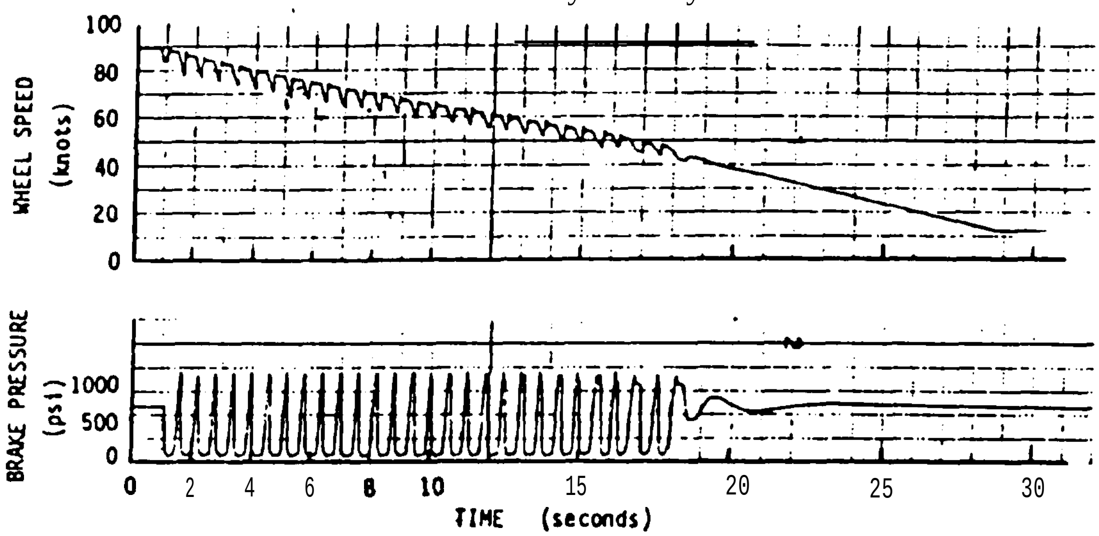
(4) Fully modulating systems are a further refinement of the quasi-modulating systems. The major difference between these two types of anti-skid systems is in the implementation of the skid control logic. During a skid, corrective action is based on the sensed wheel speed signal, rather than a pre-programmed response. Specifically, the amount of pressure reduction or reapplication is based on the rate at which the wheel is going into or recovering from a skid.

(5) In addition to examining the control system for the differences noted above, a time history of the response characteristics of the anti-skid system during a wet runway stop should be used to help identify the type of anti-skid system. Comparing the response characteristics between wet and dry runway stops can also be helpful.

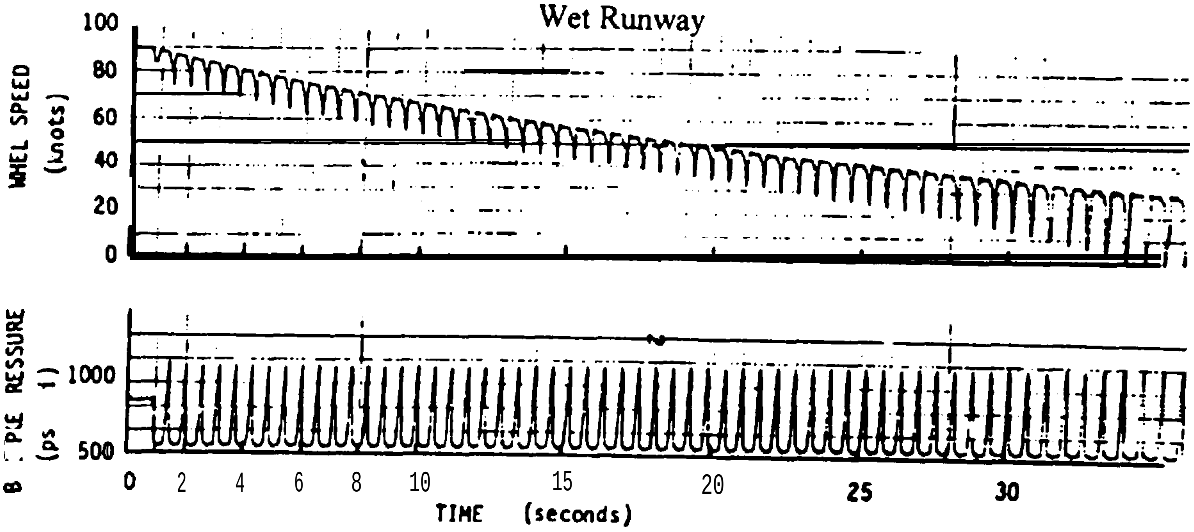
(6) Figure 1 l-3 shows an example of the response characteristics of a typical on-off system on both dry and wet runways. In general, the on-off system exhibits a cyclic behavior of brake pressure application until a skid is sensed, followed by the complete release of brake pressure to allow the wheel to spin back up. Full-metered pressure (as commanded by the pilot) is then re-applied, starting the cycle over again. The wheel speed trace exhibits deep and frequent skids (the troughs in the wheel speed trace), and the average wheel speed is significantly less than the synchronous speed (which is represented by the flat-topped portions of the wheel speed trace). Note that the skids are deeper and more frequent on a wet runway than on a dry runway. For the particular example shown in Figure 1 l-3, the brake becomes torque-limited toward the end of the dry runway stop, and is unable to generate enough torque to cause further skidding.

FIGURE 11-3. ANTI-SKID SYSTEM RESPONSE CHARACTERISTICS
On-Off System

Dry Runway



Wet Runway

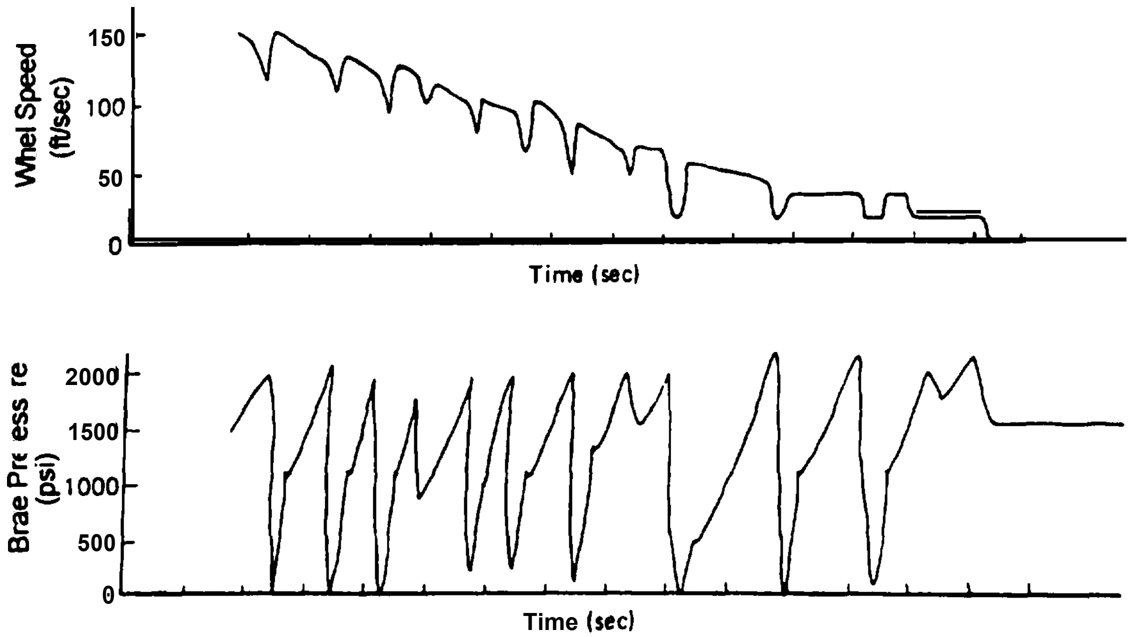


(7) The effectiveness of quasi-modulating systems can vary significantly depending on the slipperiness of the runway and the design of the particular control system. On dry runways, these systems typically perform very well; however, on wet runways their performance is highly dependent on the design and tuning of the particular system. An example of the response characteristics of one such system is shown in Figure 11-4. On both dry and wet runways, brake pressure is released to the extent necessary to control skidding. As the wheel returns to the synchronous speed, brake pressure is quickly increased to a pre-determined level and then gradually ramped up to the full-metered brake pressure. On a dry runway, this type of

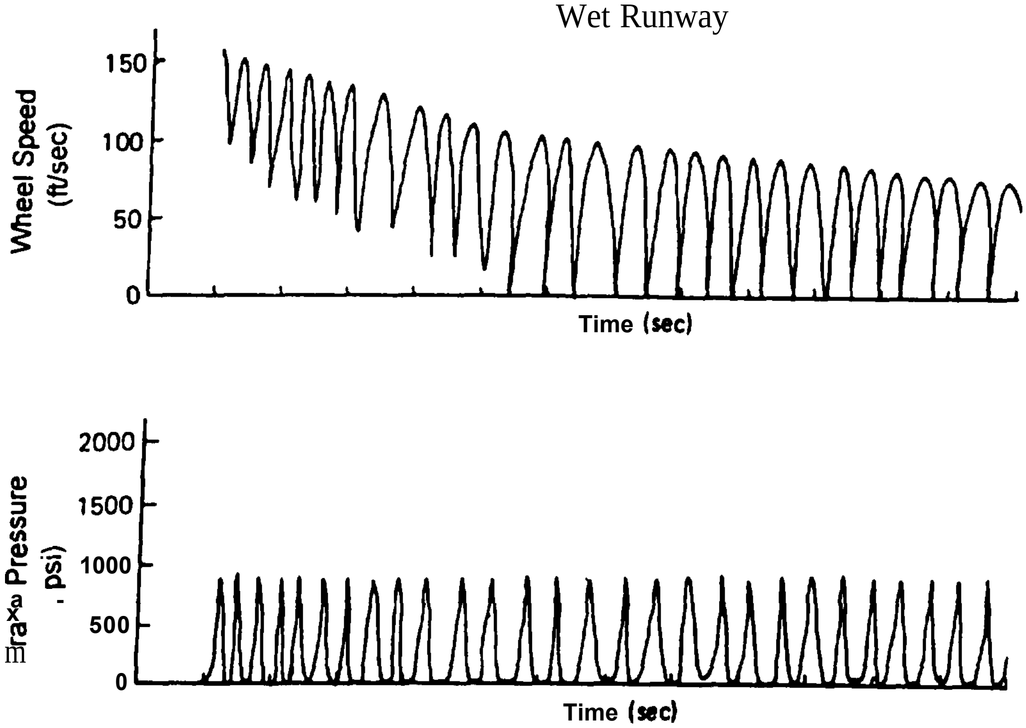
response reduces the depth and frequency of skidding compared to an on-off system. However, on a wet runway, skidding occurs at a pressure below that at which the gradual ramping of brake pressure occurs. As a result, on wet runways the particular system shown in Figure 1 l-4 operates very similarly to an on-off system.

FIGURE 11-4. ANTI-SKID SYSTEM RESPONSE CHARACTERISTICS
Quasi-Modulating System

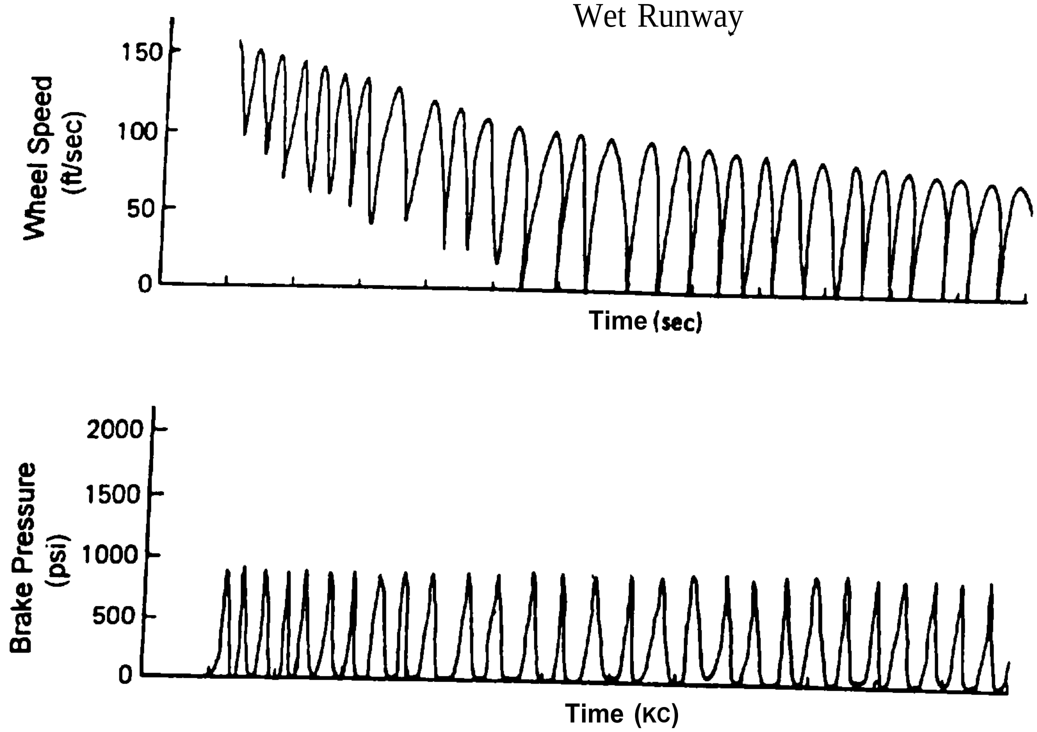
Dry Runway



Wet Runway



Wet Runway

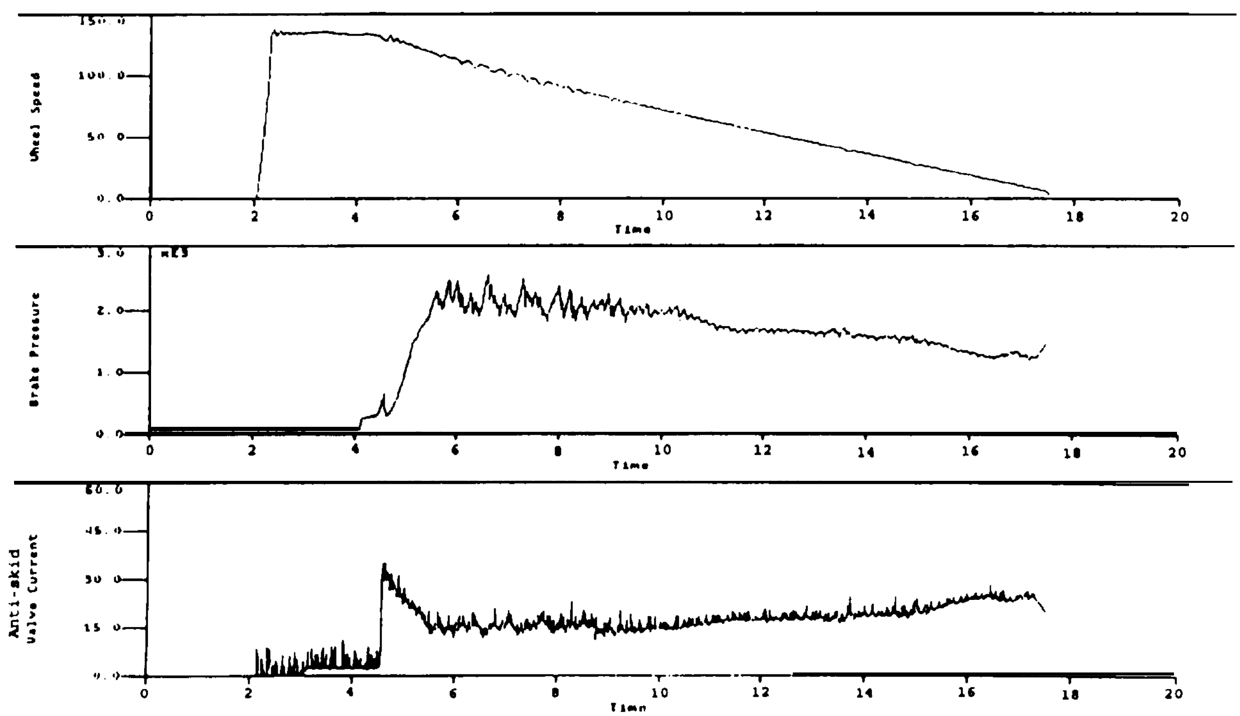


(8) When properly tuned, fully modulating systems are characterized by much smaller variations% brake pressure around a fairly high average value. These systems can respond quickly to developing skids, and are capable of modulating brake pressure to reduce the frequency and depth of skidding. As a result, the average wheel speed remains much closer to the synchronous wheel speed. Figure 11-5 illustrates an example of the response characteristics of a fully modulating system on dry and wet runways.

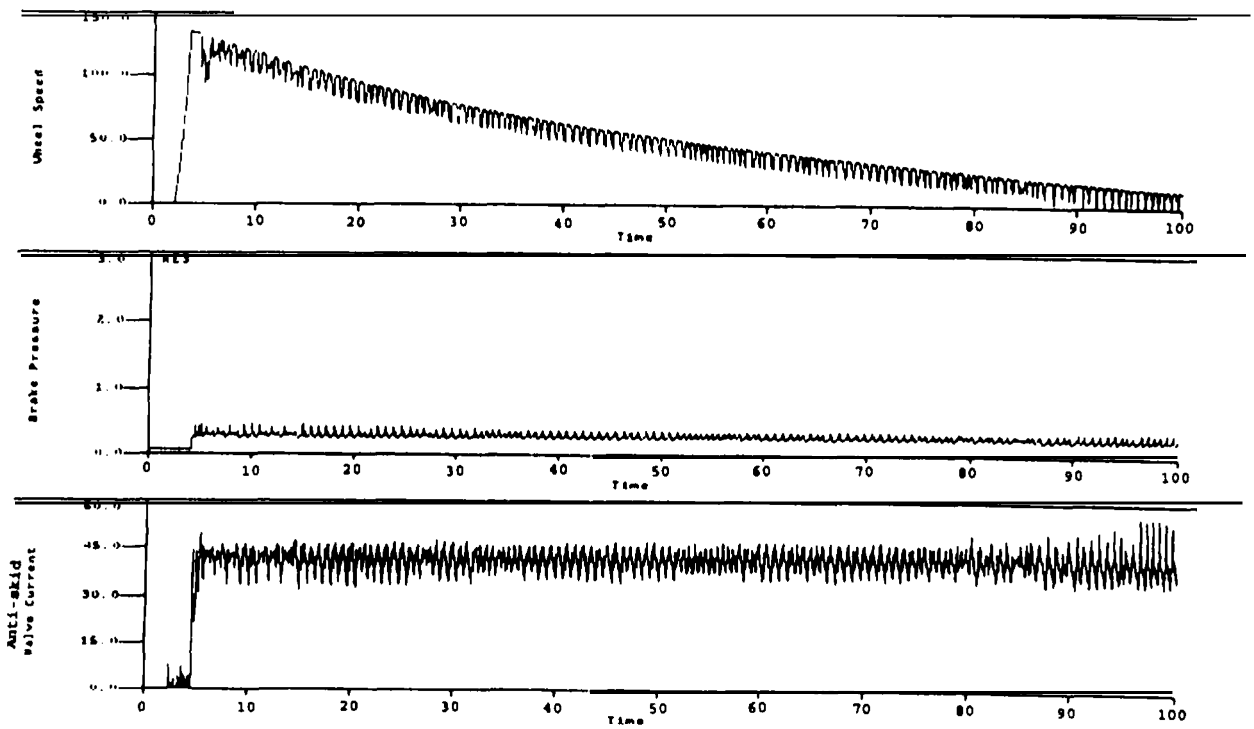
FIGURE 1 l-5. ANTI-SKID SYSTEM RESPONSE CHARACTERISTICS

Fully Modulating System

Dry Runway



Wet Runway



(B) Demonstration of Anti-Skid System Operation When Using the Anti-Skid Efficiency Values Specified in § 25.109(c)(2).

(1) If the applicant elects to use one of the anti-skid efficiency values specified in § 25.109(c)(2), a limited amount of flight testing must still be conducted to verify that the anti-skid system operates in a manner consistent with the type of anti-skid system declared by the applicant. This testing should also demonstrate that the anti-skid system has been properly tuned for operation on wet runways.

(2) A minimum of one complete stop, or equivalent segmented stops, should be conducted on a smooth (i.e., not grooved or porous friction course) wet runway at an appropriate speed and energy to cover the critical operating mode of the anti-skid system. Since the objective of the test is to observe the operation (Le., cycling) of the anti-skid system, this test will normally be conducted at an energy well below the maximum brake energy condition.

(3) The section of the runway used for braking should be well soaked (i.e., not just damp), but not flooded. The runway test section should be wet enough to result in a number of cycles of anti-skid activity, but should not cause hydroplaning.

(4) Before taxi and with cold tires, the tire pressure should be set to the highest value appropriate to the takeoff weight for which approval is being sought.

(5) The tires and brakes should not be new, but need not be in the fully worn condition. They should be in a condition considered representative of typical in-service operations.

(6) Sufficient data should be obtained to determine whether the system operates in a manner consistent with the type of anti-skid system declared by the applicant, provide evidence that full brake pressure is being applied upstream of the anti-skid valve during the flight test demonstration, determine whether the anti-skid valve is performing as intended, and show that the anti-skid system has been properly tuned for a wet runway. Typically, the following parameters should be plotted versus time:

(i) The speed of a representative number of wheels.

(ii) The hydraulic pressure at each brake (i.e., the hydraulic pressure downstream of the anti-skid valve or the electrical input to each anti-skid valve).

(iii) The hydraulic pressure at each brake metering valve (i.e., upstream of the anti-skid valve).

(7) A qualitative assessment of anti-skid system response and airplane controllability should be made by the test pilot(s). In particular, pilot observations should confirm that:

(i) Anti-skid releases are neither excessively deep nor prolonged;

(ii) The landing gear is free of unusual dynamics; and

(iii) The airplane tracks essentially straight, even though runway seams, water puddles, and wetter patches may not be uniformly distributed in location or extent.

(C) Determination of a Specific Wet Runway Anti-Skid System Efficiency.

(1) If the applicant elects to derive the anti-skid system efficiency from flight test demonstrations, sufficient flight testing, with adequate instrumentation, must be conducted to ensure confidence in the value obtained. An anti-skid efficiency of 92 percent (i.e., a factor of 0.92) is considered to be the maximum efficiency on a wet runway normally achievable with fully modulating digital anti-skid systems.

(2) A minimum of three complete stops, or equivalent segmented stops, should be conducted on a wet runway at appropriate speeds and energies to cover the critical operating modes of the anti-skid system. Alternatively, if the operation and efficiency of the anti-skid system on a wet runway can be predicted by laboratory simulation data and validated by flight test demonstrations, a lesser number of stops may be acceptable. In this case, as many complete stops, or equivalent segmented stops, as necessary to present six independent anti-skid efficiency calculations should be conducted on a wet runway at appropriate speeds and energies

to cover the critical operating modes of the anti-skid system. An independent anti-skid efficiency calculation can be presented for each stop for each independently controlled wheel, or set of wheels.

(3) Since the objective of the test is to determine the efficiency of the anti-skid system, these tests will normally be conducted at energies well below the maximum brake energy condition. A sufficient range of speeds should be covered to investigate any variation of the anti-skid efficiency with speed.

(4) The testing should be conducted on a smooth (i.e., not grooved or porous friction course) runway. If the applicant chooses to determine accelerate-stop distances for grooved and porous friction course (PFC) surfaces under § 25.109(d)(2), testing should also be conducted on a grooved or porous friction course runway to determine the anti-skid efficiency value applicable to those surfaces. Other means for determining the anti-skid efficiency value for grooved and PFC surfaces may also be acceptable, such as using the efficiency value previously determined for smooth runways, if that value is shown to also be representative of or conservative for grooved and PFC runways.

(5) The section of the runway used for braking should be well soaked (i.e., not just damp), but not flooded. The runway test section should be wet enough to result in a number of cycles of anti-skid activity, but should not cause hydroplaning.

(6) Before taxi and with cold tires, the tire pressure should be set to the highest value appropriate to the takeoff weight for which approval is being sought.

(7) The tires and brakes should not be new, but need not be in the fully worn condition. They should be in a condition considered representative of typical in-service operations.

(8) A qualitative assessment of anti-skid system response and airplane controllability should be made by the test pilot(s). In particular, pilot observations should confirm that:

(i) The landing gear is free of unusual dynamics; and

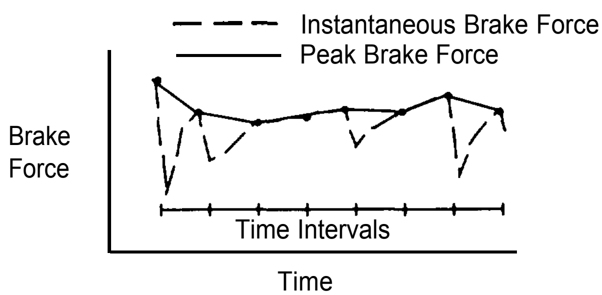
(ii) The airplane tracks essentially straight, even though runway seams, water puddles, and wetter patches may not be uniformly distributed in location or extent.

(9) Two acceptable methods, referred to as the torque method and the wheel slip method, for determining the wet runway anti-skid efficiency value from wet runway stopping tests are described below. Other methods may also be acceptable if they can be shown to give equivalent results. The test instrumentation and data collection should be consistent with the method used.

(i) <u>Torque Method</u>:

(i) Under the torque method, the anti-skid system efficiency is determined by comparing the energy absorbed by the brake during an actual wet runway stop to the energy that is determined by integrating, over the stopping distance, a curve defined by connecting the peaks of the instantaneous brake force curve (see Figure 1 l-6). The energy absorbed by the brake during the actual wet runway stop is determined by integrating the curve of instantaneous brake force over the stopping distance.

FIGURE 1 l-6. INSTANTANEOUS BRAKE FORCE AND PEAK BRAKE FORCE



(b) Using data obtained from the wet runway stopping tests of paragraph 11 c(4)(ii)(C), instantaneous brake force can be calculated from the following relationship:

$$F_b = \frac{(T_b + \alpha I)}{R_{tire}}$$

where:	Fb	= brake force
	T_b	= brake torque
	a	= wheel acceleration
	I	= wheel and tire moment of inertia
and	R_{tire}	= tire radius.

(c) For brake installations where measuring brake torque directly is impractical, torque may be determined from other parameters (e.g., brake pressure) if a suitable correlation is available. Wheel acceleration is obtained from the first derivative of wheel speed. Instrumentation recording rates and data analysis techniques for wheel speed and torque data should be well matched to the anti-skid response characteristics to avoid introducing noise and other artifacts of the instrumentation system into the data.

(d) Since the derivative of wheel speed is used in calculating brake force, smoothing of the wheel speed data is usually necessary to give good results. The smoothing algorithm should be carefully designed as it can affect the resulting efficiency calculation. Filtering or smoothing of the brake torque or brake force data should not normally be done. If conditioning is applied, it should be done in a conservative manner (i.e., result in a lower efficiency value) and should not misrepresent actual airplane/system dynamics.

(e) Both the instantaneous brake force and the peak brake force should be integrated over the stopping distance. The anti-skid efficiency value for determining the wet runway accelerate-stop distance is the ratio of the instantaneous brake force integral to the peak brake force integral:

$$\text{anti - skid efficiency} = \frac{\int \text{instantaneous brake force. ds}}{\int \text{peak brake force. ds}}$$

where s = stopping distance

(f) The stopping distance is defined as the distance traveled during the specific wet runway stopping demonstration, beginning when the full braking configuration is obtained and ending at the lowest speed at which anti-skid cycling occurs (i.e., the brakes are not torque-limited), except that this speed need not be less than 10 knots. Any variation in the anti-skid efficiency with speed should also be investigated, which can be accomplished by determining the efficiency over segments of the total stopping distance. If significant variations are noted, this variation should be reflected in the braking force used to determine the accelerate-stop distances (either by using a variable efficiency or by using a conservative single value).

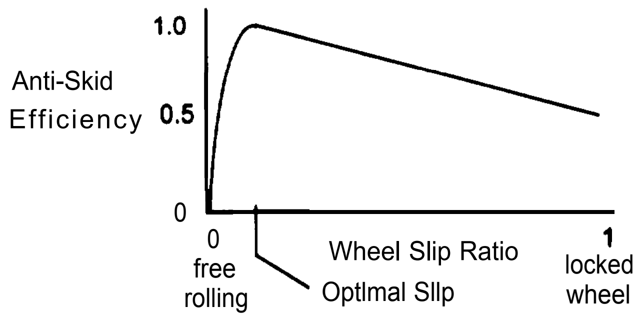
(ii) Wheel Slip Method:

(a) At brake application, the tire begins to slip with respect to the runway surface (i.e., the wheel speed slows down with respect to the airplane's ground speed). As the amount of tire slip increases, the brake force also increases until an optimal slip is reached. If the amount of slip continues to increase past the optimal slip, the braking force will decrease.

(b) Using the wheel slip method, the anti-skid efficiency is determined by comparing the actual wheel slip measured during a wet runway stop to the optimal slip. Since the wheel slip varies significantly during the stop, sufficient wheel and ground speed data must be obtained to determine the variation of both the actual wheel slip and the optimal wheel slip over the length of the stop. A sampling rate of at least 16 samples per second for both wheel speed and ground speed has been found to yield acceptable fidelity.

(c) For each wheel and ground speed data point, the instantaneous anti-skid efficiency value should be determined from the relationship shown in Figure 1 l-7.

FIGURE 11-7. ANTI-SKID EFFICIENCY - WHEEL SLIP RELATIONSHIP



for WSR < OPS Efficiency $= 1.5\left(\frac{WSR}{OPS}\right) - 0.5\left(\frac{WSR}{OPS}\right)$

WSR = OPS Efficiency = 1 .O

WSR > OPS Efficiency $= 0.5\left(1 + \frac{(1 - WSR)}{(1 - OPS)}\right)$

where WSR = the wheel slip ratio $= 1 - \left(\frac{\text{Wheel speed}}{\text{Ground speed}}\right)$

and OPS is the optimal slip ratio

(d) To determine the overall anti-skid efficiency value for use in calculating the wet runway accelerate-stop distance, the instantaneous anti-skid efficiencies should be integrated with respect to distance and divided by the total stopping distance:

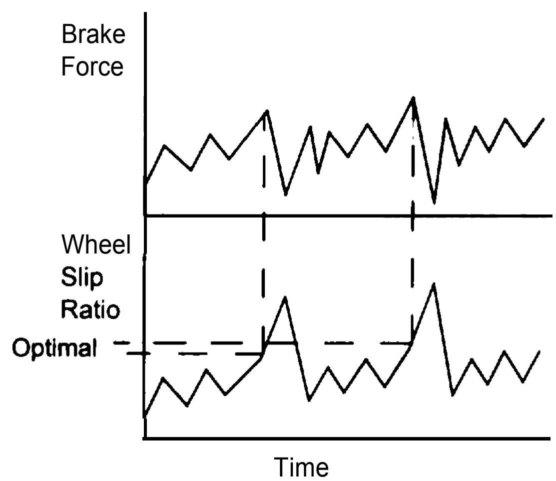
$$\text{anti - skid efficiency} = \frac{\int \text{instantaneous efficiency} \cdot ds}{s}$$

where s = stopping distance

(e) The stopping distance is defined as the distance traveled during the specific wet runway stopping demonstration, beginning when the full braking configuration is obtained and ending at the lowest speed at which anti-skid cycling occurs (Le., the brakes are not torque-limited), except that this speed need not be less than 10 knots. Any variation in the anti-skid efficiency with speed should also bo investigated, which can be accomplished by determining the efficiency over segments of the total stopping distance. If significant variations are noted, this variation should be reflected in the braking force used to determine the accelerate-stop distances (either by using a variable efficiency or by using a conservative single value).

(f) The applicant should provide substantiation of the optimal wheel slip value(s) used to determine the anti-skid efficiency value. An acceptable method for determining the optimal slip value(s) is to compare time history plots of the brake force and wheel slip data obtained during the wet runway stopping tests. For brake installations where measuring brake force directly is impractical, brake force may be determined from other parameters (e.g., brake pressure) if a suitable correlation is available. For those skids where wheel slip continues to increase after a reduction in the brake force, the optimal slip is the slip value corresponding to the brake force peak. See Figure 1 l-8 for an example and note how both the actual wheel slip and the optimal wheel slip can vary during the stop.

FIGURE 1 l-8. SUBSTANTIATION OF THE OPTIMAL SLIP VALUE



(D) For dispatch with an inoperative anti-skid system (if approved), the wet runway accelerate-stop distances should be based on an efficiency no higher than that allowed by § 25.109(c)(2) for an on-off type of anti-skid system. The safety of this type of operation should be demonstrated by flight tests conducted in accordance with paragraph 1 lc(4)(ii)(B).

(iii) Distribution of the Normal Load Between Braked and Unbraked Wheels, In addition to taking into account the efficiency of the anti-skid system, § 25.109(b)(2)(ii) also requires adjusting the braking force for the effect of the distribution of the normal load between braked and unbraked wheels at the most adverse center-of-gravity position approved for takeoff. The stopping force due to braking is equal to the braking coefficient multiplied by the normal load (i.e., weight) on each braked wheel. The portion of the airplane's weight being supported by the unbraked wheels (e.g., unbraked nose wheels) does not contribute to the stopping force generated by the brakes. This effect must be taken into account for the most adverse center-of-gravity position approved for takeoff, considering any redistribution in loads that occur due to the dynamics of the stop. The most adverse center-of-gravity position is the position that results in the least load on the braked wheels.

(iv) Grooved and Porous Friction Course (PFC) Runways. Properly designed, constructed, and maintained grooved and PFC runways can offer significant improvements in wet runway braking capability. A conservative level of performance credit is provided by § 25.109(d) to reflect this performance improvement and to provide an incentive for installing and maintaining such surfaces.

(A) In accordance with §§ 25.105(c) and 25.109(d), applicants may optionally determine the accelerate-stop distance applicable to wet grooved and PFC runways. These data would be included in the AFM in addition to the smooth runway accelerate-stop distance data. The braking coefficient for determining the accelerate-stop distance on grooved and PFC runways is defined in § 25.109(d) as either 70 percent of the braking coefficient used to determine the dry runway accelerate-stop distances, or a curve based on ESDU 71026 data and derived in a manner consistent with that used for smooth runways. In either case, the brake torque limitations determined on a dry runway may not be exceeded.

(B) Using a simple factor applied to the dry runway braking coefficient is acceptable for grooved and PFC runways because the braking coefficient's variation with speed is much lower on these types of runways. On smooth wet runways, the braking coefficient varies significantly with speed, which makes it inappropriate to apply a simple factor to the dry runway braking coefficient.

(C) For applicants who choose to determine the grooved/PFC wet runway accelerate-stop distances in a manner consistent with that used for smooth runways, § 25.109(d)(2) provides the maximum tire-to-ground braking coefficient applicable to grooved and PFC runways. This maximum tire-to-ground braking coefficient must be adjusted for the anti-skid system efficiency, either by using the value specified in § 25.109(c)(2) appropriate to the type of anti-skid system installed, or by using a specific efficiency established by the applicant. As anti-skid system performance depends on the characteristics of the runway surface, a system that has been tuned for optimum performance on a smooth surface may not achieve the same level of efficiency on a grooved or porous friction course runway, and vice versa. Consequently, if the applicant elects to establish a specific efficiency for use with grooved or PFC surfaces, anti-skid efficiency testing should be conducted on a wet runway with such a surface, in addition to testing on a smooth runway. Means other than flight testing may be acceptable, such as using the efficiency previously determined for smooth wet runways, if that efficiency is shown to be representative of, or conservative for, grooved and PFC runways. The resulting braking force for grooved/PFC wet runways must be adjusted for the effect of the distribution of the normal load between braked and unbraked wheels. This adjustment will be similar to that used for determining the braking force for smooth wet runways, except that the braking dynamics should be appropriate to the braking force achieved on grooved and PFC wet runways. Due to the increased braking force on grooved and PFC wet runways, an increased download on the nose wheel and corresponding reduction in the download on the main gear is expected.

(D) In accordance with §§ 25.1533(a)(3) and 25.1583(h), grooved and PFC wet runway accelerate-stop distances may be established as operating limitations and be presented in the AFM, but approval to use these distances is limited to runways that have been designed, constructed, and maintained in a manner acceptable to the FAA Administrator. Airplane operators who wish to use the grooved or PFC runway accelerate-stop distances must determine that the design, construction, and maintenance aspects are acceptable for each runway for which such credit is sought. Advisory Circular 150/5320-12C, "Measurement, Construction, and Maintenance of Skid-Resistant Airport Pavement Surfaces," provides guidance relative to acceptable design, construction, and maintenance practices for grooved and PFC runway surfaces.

(v) Reverse thrust performance credit. In accordance with § 25.109(f), reverse thrust may not be used to determine the accelerate-stop distances for a dry runway. For wet runway accelerate-stop distances, however, § 25.109(f) allows credit for the stopping force provided by reverse thrust, if the requirements of $25.109(e) are met. In addition, the procedures associated with the use of reverse thrust, which § 25.101(f) requires the applicant to provide, must meet the requirements of § 25.101 (h). The following criteria provide acceptable means of demonstrating compliance with these requirements:

(A) Procedures for using reverse thrust during a rejected takeoff must be developed and demonstrated. These procedures should include all of the pilot actions necessary to obtain the recommended level of reverse thrust, maintain directional control and safe engine operating characteristics, and return the reverser(s), as applicable, to either the idle or the stowed position. These procedures need not be the same as those recommended for use during a landing stop, but must not result in additional hazards (e.g., cause a flameout or any adverse engine operating characteristics), nor may they significantly increase flightcrew workload or training needs.

(B) It should be demonstrated that using reverse thrust during a rejected takeoff complies with the engine operating characteristics requirements of § 25.939. The engine should not exhibit any of the adverse engine operating characteristics described in AC 25.939-l) "Evaluating Turbine Engine Operating Characteristics," dated March 19, 1986 (or later revision). The reverse thrust procedures may specify a speed at which the reverse thrust is to be reduced to idle in order to maintain safe engine operating characteristics.

(C) The time sequence for the actions necessary to obtain the recommended level of reverse thrust should be demonstrated by flight test. The time sequence used to determine the accelerate-stop distances should reflect the most critical case relative to the time needed to deploy the thrust reversers. For example, on some airplanes the outboard thrust reversers are locked out if an outboard engine fails. This safety feature prevents the pilot from applying asymmetric reverse thrust on the outboard engines, but it may also delay the pilot's selection of reverse thrust on the operable reversers. In addition, if the selection of reverse thrust is the fourth or subsequent pilot action to stop the airplane (e.g., after manual brake application, thrust/power reduction, and spoiler deployment), a one-second delay should be added to the demonstrated time to select reverse thrust (see Figure 11-l).

(D) The response times of the affected airplane systems to pilot inputs should be taken into account. For example, delays in system operation, such as thrust reverser interlocks that prevent the pilot from applying reverse thrust until the reverser is deployed, should be taken into account. The effects of transient response characteristics, such as reverse thrust engine spin-up, should also be included.

(E) To enable a pilot of average skill to consistently obtain the recommended level of reverse thrust under typical in-service conditions, a lever position that incorporates tactile feedback (e.g., a detent or stop) should be provided. If tactile feedback is not provided, a conservative level of reverse thrust should be assumed.

(F) The applicant should demonstrate that exceptional skill is not required to maintain directional control on a wet runway with a ten-knot crosswind from the most adverse direction. For demonstration purposes, a wet runway may be simulated by using a nosewheel free to caster on a dry runway. Symmetric braking should be used during the demonstration, and both all-engines-operating and critical-engine-inoperative reverse thrust should be considered. The brakes and thrust reversers may not be modulated to maintain directional control, The reverse thrust procedures may specify a speed at which the reverse thrust is reduced to idle in order to maintain directional controllability.

(G) Compliance with the requirements of §§ 25.901(b)(2), 25.901(c), 25.1309(b), and 25.1309(c) will be accepted as providing compliance with the "safe and reliable" requirements of §§ 25.101(h)(2) and 25.109(e)(1).

(H) The number of thrust reversers used to determine the wet runway accelerate-stop distance data provided in the AFM should reflect the number of engines assumed to be operating during the rejected takeoff, along with any applicable system design features. The all-engines-operating accelerate-stop distances should be based on all thrust reversers operating, The one-engine-inoperative accelerate-stop distances should be based on failure of the critical engine. For example, if the outboard thrust reversers are locked out when an outboard engine fails, the one-engine-inoperative accelerate stop distances can only include reverse thrust from the inboard engine thrust reversers.

(I) For the engine failure case, it should be assumed that the thrust reverser does not deploy (i.e., no reverse thrust or drag credit for deployed thrust reverser buckets on the failed engine).

(J) For approval of dispatch with one or more inoperative thrust reverser(s), the associated performance information should be provided either in the AFM or the Master Minimum Equipment List.

(K) The effective stopping force provided by reverse thrust in each, or at the option of the applicant, the most critical takeoff configuration, should be demonstrated by flight test. (One method of determining the reverse thrust stopping force would be to compare unbraked runs with and without the use of thrust reversers.) Regardless of the method used to demonstrate the effective stopping force provided by reverse thrust, flight test demonstrations should be conducted using all of the stopping means on which the AFM wet runway accelerate-stop distances are based in order to substantiate the accelerate-stop distances and ensure that no adverse combination effects are overlooked. These demonstrations may be conducted on a dry runway.

(L) For turbopropeller powered airplanes, the criteria of paragraphs (A) through (K) above remain generally applicable. Additionally, the propeller of the inoperative engine should be in the position it would normally assume when an engine fails and the power lever is closed. Reverse thrust may be selected on the remaining engine(s). Unless this selection is achieved by a single action to retard the power lever(s) from the takeoff setting without encountering a stop or lockout, it should be regarded as an additional pilot action for the purposes of assessing delay times. If this action is the fourth or subsequent pilot action to stop the airplane, a one-second delay must be added to the demonstrated time to select reverse thrust.

(vi) Airplane Flight Manual (AFM) wet runway accelerate-stop distances. Section 25.1583(h) requires the operating limitations established under § 25.1533, including wet runway accelerate-stop distances, to be presented in the AFM. At the option of the applicant, grooved and PFC wet runway accelerate-stop distances may also be presented in the AFM, but approval to use these distances is limited to runways that have been designed, constructed, and maintained in a manner acceptable to the FAA Administrator. The page(s) in the AFM containing the wet runway accelerate-stop distances for grooved and PFC runways should contain a note equivalent to the following: "These accelerate-stop distances apply only to runways that are grooved or treated with a porous friction course (PFC) overlay that the operator has determined have been designed, constructed, and maintained in a manner acceptable to the FAA Administrator." Information should also be included describing the method and assumptions used in generating both the smooth and grooved/PFC wet runway information and generally describing the effect of operational variables on wet runway stopping performance (e.g., tire tread depth, runway surface texture, water depth, brakes-on speed).

12. TAKEOFF PATH - § 25.111.

a. Section 25.111 (a).

(1) Explanation.

(i) The takeoff path requirements of § 25.111, and the reductions to that path required by § 25.115, are established so that the AFM performance can be used in making necessary decisions relative to takeoff weights when obstacles are present. Such considerations are required by § 12 1.189 when operations are conducted in accordance with 14 CFR part 12 1.

(ii) The required performance is provided in AFMs by either pictorial paths at various thrust-to-weight (T/W) conditions, with corrections for wind, or by a series of charts for each segment, along with a procedure for connecting these segments into a continuous path.

(2) Procedures.

(i) Section 25.1 1 l(a) requires that the actual takeoff path (from which the AFM net takeoff flight path is derived) extend to the higher of where the airplane is 1,500 ft. above the takeoff surface or to the altitude at which the transition to en route configuration is complete and a speed is reached where compliance with the final segment requirements of § 25.12 l (c) can be met. Section 25.115(b) allows termination of the AFM "net" flight path below 1,500 ft. in some cases.

(ii) The AFM should contain information required to show compliance with the climb requirements of §§ 25.111 and 25.12 1 (c). This should include information related to the transition from the takeoff configuration and speed to the final segment configuration and speed. The effects of changes from takeoff thrust to maximum continuous thrust should also be included.

(iii) Generally, the AFM shows low T/W takeoff paths ending at 1500 ft. above the takeoff surface, with acceleration segments between 400 and 1,500 ft., and high T/W takeoff paths extending considerably higher than 1,500 ft. above the takeoff surface. On some airplanes, the takeoff speed schedules, or certain flap configurations, do not require acceleration below 1,500 ft., even at limiting performance gradients. Although § 25.11 I(a) permits the takeoff path to be terminated as low as 1,500 feet above the takeoff surface, it is recommended that the flight path data, or associated AFM methodology, be presented so that the flight path can be determined to 3,000 ft. above the takeoff surface. This will permit obstacle clearance analysis for distant obstacles of considerable elevation that may be encountered in operations from mountain airports.

(iv) The § 25.115(b) net takeoff flight path, required by § 25.1587(b) to be included in the AFM, need not extend to the altitude specified in § 25.11 l(a). It may be terminated at a height, generally called "NET HEIGHT," that is directly related to the actual airplane height specified in § 25.11 l(a). The "NET HEIGHT" is calculated using the actual airplane takeoff climb performance, to the point where the altitude requirements of § 25.111 (a) are met, reduced by the climb gradient decrements specified in § 25.115(b).

b. Section 25.111 (a)(l)- Takeoff Path Thrust Conditions.

(1) Explanation. The takeoff path established from continuous demonstrated takeoffs must at all points represent the actual expected performance, or be conservative, per §§ 25.11 l(d)(2) and 25.11 l(d)(4), if the path is constructed by the segmental method.

(2) Procedures.

(i) To be assured that the predicted takeoff path is representative of actual performance, the thrust used in its construction must comply with § 25.101(c). This requires, in part, that the thrust be based on the particular ambient atmospheric conditions that are assumed to exist along the path. The standard lapse rate for ambient temperature is specified in Part 1 of the FAR under "Standard Atmosphere," and should be used for thrust determination associated with each pressure altitude during the climb.

(ii) In accordance with § 25.11 l(c)(4), the thrust up to 400 ft. above the takeoff surface must represent the thrust available along the path resulting from the power lever setting established during the initial ground roll in accordance with AFM procedures. This resulting thrust may be less than that available from the rated inflight setting schedule.

(iii) A sufficient number of takeoffs, to at least the altitude above the takeoff surface scheduled for V_2 climb, should be made to establish the fixed power lever thrust lapse. An analysis may be used to account for various engine bleeds (e.g. ice protection, air conditioning, etc.). In some airplanes, the thrust growth characteristics are such that less than full rated thrust must be used for AFM takeoff power limitations and performance. This is to preclude engine limitations from being exceeded during the takeoff climbs to 400 ft. above the takeoff surface.

(iv) Engine thru s 1apse with speed and altitude during the takeoff and climb, at fixed power lever settings, can be affected by takeoff pressure altitude.

(v) Most turbine engines are sensitive to crosswind or tailwind conditions, when setting takeoff power under static conditions, and may stall or surge. To preclude this problem, it is acceptable to establish a rolling takeoff thrust setting procedure, provided the AFM takeoff field length and the takeoff thrust setting charts are based on this procedure. Demonstrations and analyses have been accepted in the past showing a negligible difference in distance between static and rolling takeoffs. A typical test procedure is as follows:

(A) After stopping on the runway, set an intermediate power on all engines (power setting selected by applicant).

(B) Release brakes and advance power levers.

(C) Set target power setting as rapidly as possible prior to reaching 60 to 80 knots.

(D) No adverse engine operating characteristics should exist after completion of the power setting through the climb to 1,500 A. above the airport and attainment of the en route configuration. Tests should be conducted to determine if any engine operating problems exist for takeoffs conducted throughout the altitude range for which takeoff operations are to be scheduled in the AFM.

(vi) If the applicant wishes to use a different procedure, it should be evaluated and, if found acceptable, the procedure should be reflected in the AFM.

c. Section 25.111 (a)(2) - Engine Failure.

(1) Explanation.

(i) Since the regulations cannot dictate what type of engine failures may actually occur, it could be assumed that the engine failure required by the regulation occurs catastrophically. Such a failure would cause the thrust to drop immediately, with the associated performance going from all-engines-operating to one-engine-inoperative at the point of engine failure.

(ii) This conservative rationale notwithstanding, there is a basis for assuming that the failed engine thrust will not decay immediately. Unlike reciprocating engines, the locking-up of a jet engine fan without causing the engine to separate from the airplane is highly unlikely. Separation of the engine or fan, or fan disintegration, would remove weight and/or the ram drag included in the engine inoperative performance, providing compensation for the immediate thrust loss.

(iii) With these considerations, it may be acceptable to use the transient thrust as the failed engine spools down at V_{EF}. The thrust time-history used for data reduction and expansion should be substantiated by test results.

(iv) In the case of propeller-driven airplanes, consideration should also be given to the position of the failed engine's propeller during the engine failure. These airplanes typically incorporate an automatic system to drive the propeller to a low drag position when an engine fails. The loss of thrust in this case will be much more sudden than the turbojet engine spooldown described above.

(2) Procedures.

(i) For turbojet powered airplanes, if transient thrust credit is used during engine failure in determining the accelerate-go AFM performance, sufficient tests should be conducted using actual fuel cuts to establish the thrust decay as contrasted to idle engine cuts. For derivative programs not involving a new or modified engine type (i.e., a modification that would affect thrust decay characteristics), fuel cuts are unnecessary if thrust decay characteristics have been adequately substantiated.

(ii) For propeller driven airplanes, the use of fuel cuts can be more important in order to ensure that the takeoff speeds and distances are obtained with the critical engine's propeller attaining the position it would during a sudden engine failure. The number of tests that should be conducted using fuel cuts, if any, depends on the correlation obtained with the idle cut data and substantiation that the data analysis methodology adequately models the effects of a sudden engine failure.

d. Section 25.111 (a)(3) - Airplane Acceleration.

(1) Explanation. None.

(2) Procedures. None.

e. Section 25.111 (b) - Airplane Rotation and Gear Retraction.

(1) Explanation. The rotation speed, V,, is intended to be the speed at which the pilot initiates action to raise the nose gear off the ground during the acceleration to V_2. Consequently, the takeoff path, determined in accordance with §§ 25.11 l(a) and (b), should assume that pilot action to raise the nose gear off the ground will not be initiated until the speed V_R has been reached.

(2) Procedures. The time between liftoff and initiation of gear retraction should not be less than that necessary to establish an indicated positive rate of climb plus one second.

f. Section 25.11 l(c)(l) - Takeoff Path Slope.

(1) Explanation.

(i) The establishment of a horizontal segment, as part of the takeoff flight path, is considered to be acceptable, per § 25.115(c), for showing compliance with the positive slope required by § 25.111 (c)(1).

(ii) The net takeoff flight path is the flight path used to determine the airplane obstacle clearance for turbine powered airplanes (§ 121,189(d)(2)). Section 25.115(b) states the required climb gradient reduction to be applied throughout the flight path for the determination of the net flight path, including the level flight acceleration segment. Rather than decreasing the level flight path by the amount required by § 25.115(b), § 25.115(c) allows the airplane to maintain a level net flight path during acceleration, but with a reduction in acceleration equal to the gradient decrement required by § 25.115(b). By this method, the applicant exchanges altitude reduction for increased distance to accelerate in level flight in determination of the level flight portion of the net takeoff path.

(2) Procedures.

(i) The level acceleration segment in the AFM net takeoff profile should begin at the same horizontal distance along the takeoff flight path that the climb segment, without the gradient reductions of § 25.115(b), reaches the AFM specified acceleration height.

(ii) The AFM acceleration height should be presented in terms of pressure altitude increment above the takeoff surface. This information should allow the establishment of the pressure altitude "increment" (Ahp) for off-standard ambient temperatures so that the geometric height required for obstacle clearance is assured. For example:

Given:

o Takeoff surface pressure altitude (hp) = 2,000 A.
o Airport std. temp. abs. (T,) = 1 $1^oC+273.2^o = 284.2^oK$
o Airport ambient temp. abs. $(T_{AM}) = -20^oC+273.2^o = 253.2^oK$
o Geometric height required (Ah) = 1,700 ft. above the takeoff surface

Find:

o Pressure altitude increment (Ahp) above the takeoff surface
Ahp = $\Delta h(T_S/T_{AM})$ = 1,700 ft. $(284.2^oK/253.2^oK)$
Ahp = 1,908 ft.

g. Section 25.111 (c)(2) - Takeoff Path Speed.

(1) Explanation.

(i) It is intended that the airplane be flown at a constant indicated airspeed to at least 400 ft. above the takeoff surface. This speed must meet the constraints on V_2 of §§ 25.107(b) and (c).

(ii) The specific wording of § 25.11 l(c)(2) should not be construed to imply that above 400 A. the airspeed may be reduced below V_2, but instead that acceleration may be commenced.

(2) Procedures.

(i) For those airplanes that take advantage of reduced stall speeds at low pressure altitude, the scheduling of V_2 should not be factored against the stall speed obtained at the takeoff surface pressure altitude. Such a procedure would result in a reduced stall speed margin during the climb, which would be contrary to the intent of § 25.107(b).

(ii) For those airplanes mentioned in paragraph (i), above, the V_2 should be constrained, in addition to the requirements of §§ 25.107(b) and (c), by the stall speed 1,500 ft. above the takeoff surface. Weight reduction along the takeoff path, due to fuel burn, may be considered in the calculation of the stall speed ratios, provided it is well established. However, many applicants have measured stall speeds at 10,000 to 15,000 ft., which provides stall margin conservatism at lower takeoff field pressure altitudes.

h. Section 25.11 l(c)(3) - Required Gradient.

(1) Explanation. None.

(2) Procedures. None.

i. Section 25.111 (c)(4) - Configuration Changes.

(1) Explanation,

(i) The intent of this requirement is to permit only those crew actions that are conducted routinely to be used in establishing the one-engine-inoperative takeoff path. The power levers may only be adjusted early during the takeoff roll, as discussed in paragraph 12b(2), and then left fixed until at least 400 ft. above the takeoff surface.

(ii) Simulation studies and accident investigations have shown that when heavy workload occurs in the cockpit, as with an engine failure during takeoff, the crew might not advance the operative engines to avoid the ground, even if the crew knows the operative engines have been set at reduced power. This same finding applies to manually feathering a propeller. The landing gear may be retracted, however, as this is accomplished routinely once a positive rate of climb is observed. This also establishes the delay time to be used for data expansion purposes.

(2) Procedures.

(i) To permit the takeoff to be conducted using less than rated power, automatic power advance devices have been approved. These devices are addressed in § 25.904, and the related performance requirements are described in Appendix I to Part 25 of the FAR.

(ii) To permit the takeoff to be based on a feathered propeller up to 400 A. above the takeoff surface, automatic propeller feathering devices have been approved. Guidance related to performance credit for automatic propeller feathering devices, below 400 feet above the takeoff surface, is presented in paragraph 241 of this AC.

(iii) Drag reduction for a manually feathered propeller is permitted for flight path calculations only after reaching 400 ft. above the takeoff surface.

j. Section 25.111 (d) - Takeoff Path Construction.

(1) Explanation. This regulation should not be construed to mean that the takeoff path be constructed entirely from a continuous demonstration or entirely from segments. To take advantage of ground effect, typical AFM takeoff paths utilize a continuous takeoff path from V_{LOF} to the gear up point, covering the range of thrust-to-weight ratios. From that point free air performance, in accordance with § 25.11 l(d)(2), is added segmentally. This methodology may yield an AFM flight path that is steeper with the gear down than up.

(2) Procedures. The AFM should include the procedures necessary to achieve this performance.

k. Section 25.11 l(d)(1) - Takeoff Path Segment Definition.

(1) Explanation. None.

(2) Procedures. None.

l. Section 25.111 (d)(2) - Takeoff Path Segment Conditions.

(1) Explanation. The subject paragraph states "The weight of the airplane, the configuration, and the power or thrust setting must be constant throughout each segment and must correspond to the most critical condition prevailing in the segment." The intent is that, for simplified analysis, the performance must be based on that value available at the most critical point in time during the segment, not that the individual variables (weight, approximate thrust setting, etc.) should each be picked at their most critical value and then combined to produce the performance for the segment.

(2) Procedures. The performance during the takeoff path segments should be obtained using one of the following methods:

(i) The critical level of performance as explained in paragraph (1);

(ii) The average performance during the segment; or

(iii) The actual performance variation during the segment.

m. Section 25.111 (d)(3) - Segmented Takeoff Path Ground Effect.

(1) Explanation. This requirement does not intend the entire flight path to necessarily be based upon out-of-ground-effect performance simply because the continuous takeoff demonstrations have been broken into sections for data reduction expediency. For example, if

the engine inoperative acceleration from V_{EF} to V_R is separated into a thrust decay portion and a windmilling drag portion, the climb from 35 A. to gear up does not necessarily need to be based upon out-of-ground-effect performance. (Also see explanation under § 25.111 (d) in paragraph 12j(1) of this AC.)

(2) Procedures. None

n. Section 25.111 (d)(4) - Segmented Takeoff Path Check.

(1) Explanation. None.

(2) Procedures. If the construction of the takeoff path from brake release to out-of-ground-effect contains any portions that have been segmented (e.g., airplane acceleration segments with all-engines-operating and one-engine-inoperative), the path should be checked by continuous demonstrated takeoffs. A sufficient number of these, employing the AFM established takeoff procedures and speeds and covering the range of thrust-to-weight ratios, should be made to ensure the validity of the segmented takeoff path. The continuous takeoff data should be compared to takeoff data calculated by AFM data procedures but using test engine thrusts and test speeds.

o. Section 25.11 l(e) - Flight Path with Standby Power Rocket Engines. (RESERVED).

* 13. TAKEOFF DISTANCE AND TAKEOFF RUN - § 25.113.

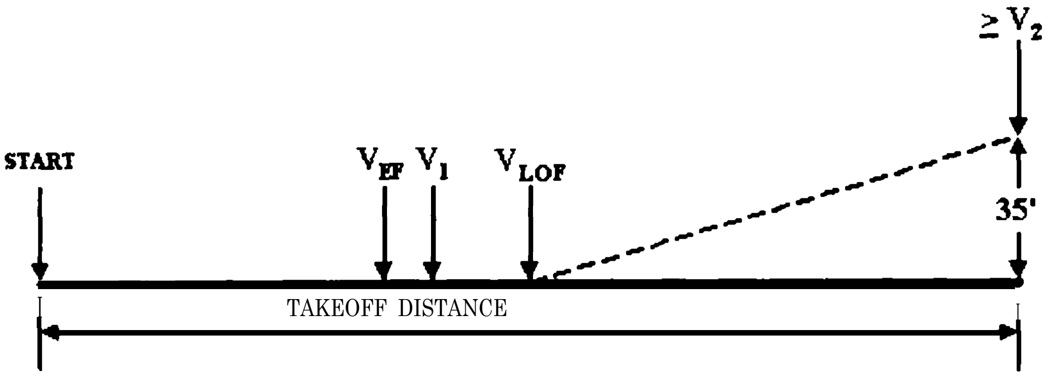
a. Takeoff Distance on a Dry Runway - § 25.113(a).

(1) The takeoff distance on a dry runway is the greater of the two distances depicted in (i) or (ii) below. The distances indicated below are measured horizontally from the main landing gears at initial brake release to that same point on the airplane when the lowest part of the departing airplane is 35 ft. above the surface of the runway.

(i) The distance measured to 35 A. with a critical engine failure occurring at V_{EF} as shown in Figure 13- 1. *

*

FIGURE 13-l. TAKEOFF DISTANCE ON A DRY RUNWAY
Critical Engine Fails at V_{EF}



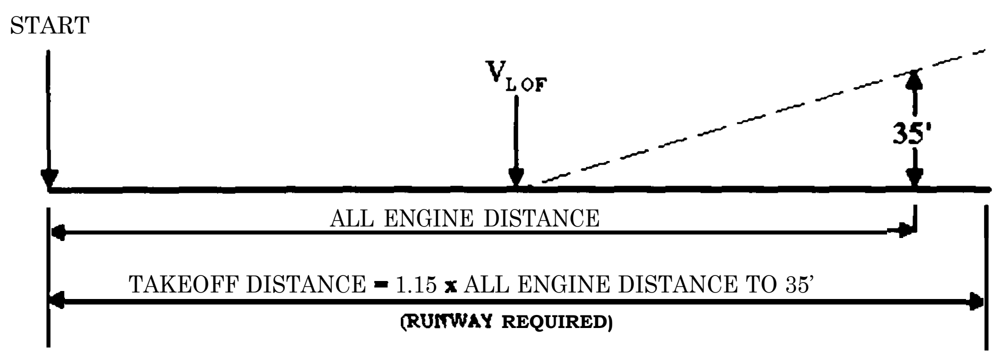
*

(ii) One hundred fifteen (115) percent of the distance measured to the 35 ft. height above the takeoff surface with all-engines-operating as shown in Figure 13-Z. In establishing the all-engines-operating takeoff distance, § 25.113(a)(2) requires the distance to be "...determined by a procedure consistent with § 25.111" (Takeoff Path). The interpretation of this statement is that the all-engines-operating takeoff distance should:

(A) Be based on the airplane reaching a speed of V_2 before it is 35 feet above the takeoff surface; and

(B) Be consistent with the achievement of a smooth transition to the steady initial climb speed at a height of 400 feet above the takeoff surface.

FIGURE 13-Z. TAKEOFF DISTANCE
(All-Engines-Operating)



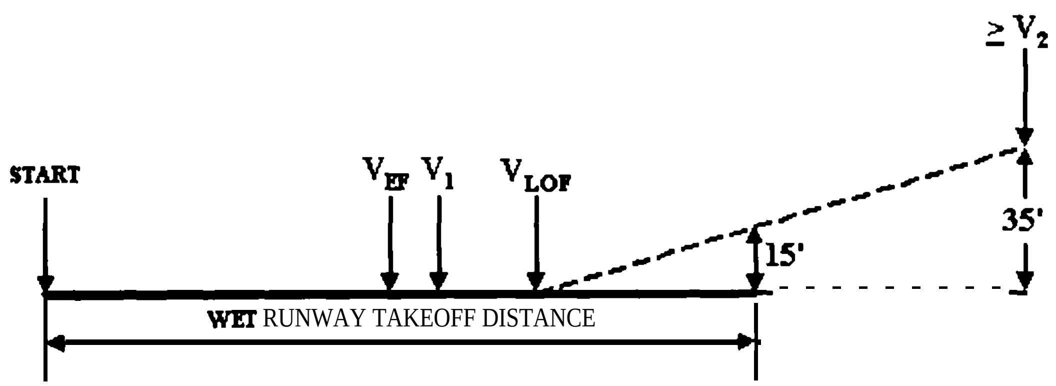
(2) The takeoff procedure adopted should be reflected in the takeoff distance.

* b. Takeoff Distance on a Wet Runway - § 25.113(b).

(1) The takeoff distance on a wet runway is the greater of the takeoff distance on a dry runway (using the dry runway V, speed), determined in accordance with paragraphs 13a(1)(i) and (ii) of this AC, or the distance on a wet runway using a reduced screen height (and the wet runway V, speed) as described in paragraph (2), below.

(2) The takeoff distance on a wet runway is determined as the horizontal distance the main landing gear travels from brake release to the point where the lowest part of the airplane is 15 A. above the takeoff surface. The airplane must attain a height of 15 ft. above the takeoff surface before reaching the end of the runway in a manner that will allow V_2 to be achieved before reaching a height of 35 ft. above the takeoff surface as shown in Figure 13-3.

FIGURE 13-3. TAKEOFF DISTANCE ON A WET RUNWAY
Critical Engine Fails at V_{EF}



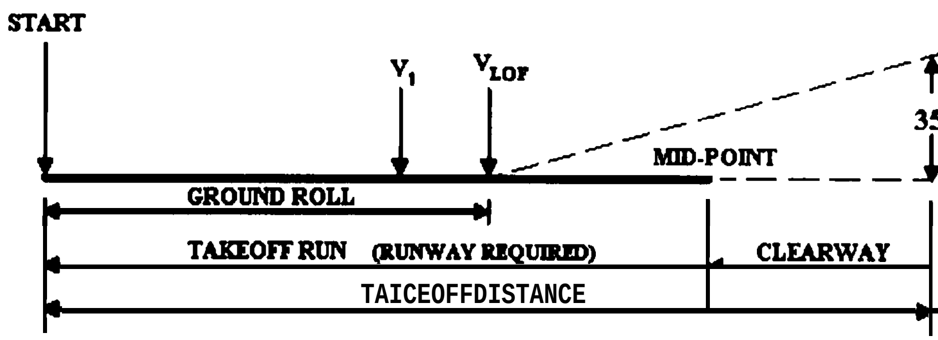
c. Takeoff Run - § 25.113(c).

(1) Takeoff run is a term used for the runway length when the takeoff distance includes a clear-way (i.e., where the accelerate-go distance does not remain entirely over the runway), and the takeoff run is either of the two distances depicted in (i) or (ii) below, whichever is greater. These distances are measured as described in § 25.113(a). When using a clearway to determine the takeoff run, no more than one half of the air distance from V_{LOF} to V_{35} may be flown over the clearway.

(i) The distance from the start of the takeoff roll to the mid-point between liftoff and the point at which the airplane attains a height of 35 ft. above the takeoff surface, with a critical engine failure occurring at V_{EF}, as shown in Figure 13-4. For takeoff on a wet runway, the takeoff run is equal to the takeoff distance (i.e., there is no clearway credit allowed on a wet runway). *

*

FIGURE 13-4. TAKEOFF RUN
Critical Engine Fails at V_{EF}



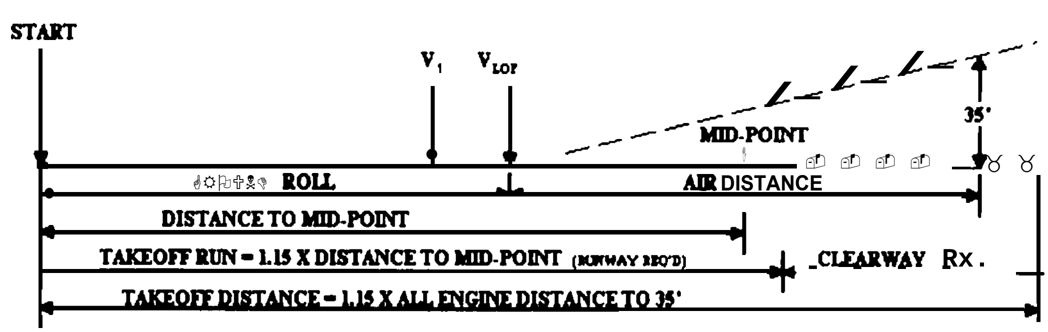
*

(ii) One hundred fifteen (115) percent of the distance from the start of the takeoff roll to the mid-point between liftoff and the point at which the airplane attains a height of 35 A. above the takeoff surface, with all engines operating, as shown in Figure 13-5. In establishing the all-engines-operating takeoff run, § 25.113(c)(2) requires the distance to be "...determined by a procedure consistent with § 25.111" (Takeoff Path). The interpretation of that statement is that the all-engines-operating takeoff run should:

(A) Be based on the airplane reaching a speed of V_2 before it is 35 feet above the takeoff surface; and

(B) Be consistent with the achievement of a smooth transition to the steady initial climb speed at a height of 400 feet above the takeoff surface.

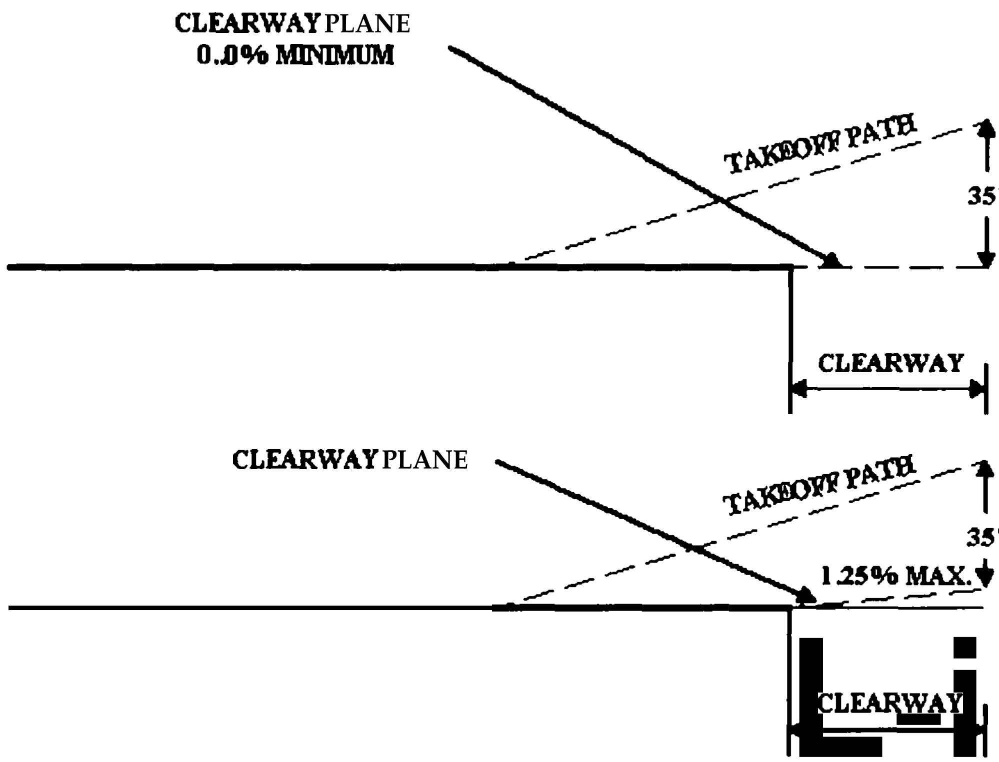
FIGURE 13-5. TAKEOFF RUN
(All-Engines-Operating)



(2) There may be situations in which the one-engine-inoperative condition (paragraph 13c(l)(i)) would dictate one of the distance criteria, takeoff run (required runway) or takeoff distance (required runway plus clearway), while the all-engines-operating condition (paragraph 13c(l)(ii)) would dictate the other. Therefore, both conditions should always be considered.

(3) Clearway is defined in 14 CFR part 1 as a plane extending from the end of the runway with an upward slope not exceeding 1.25 percent, above which no object nor any terrain protrudes. For the purpose of establishing takeoff distances and the length of takeoff runs, the clearway is considered to be part of the takeoff surface extending with the same slope as the runway, and the 35 ft. height should be measured from that surface.

FIGURE 13-6. CLEARWAY PROFILES



(4) The profile shows no fixed obstacle projecting above the clearway plane. However, the airport authorities must have control of the movable obstacles in this area to ensure that no flight will be initiated using a clearway unless it is determined with certainty that no movable obstacles will exist within the clearway when the airplane flies over.

14. TAKEOFF FLIGHT PATH - § 25.115.

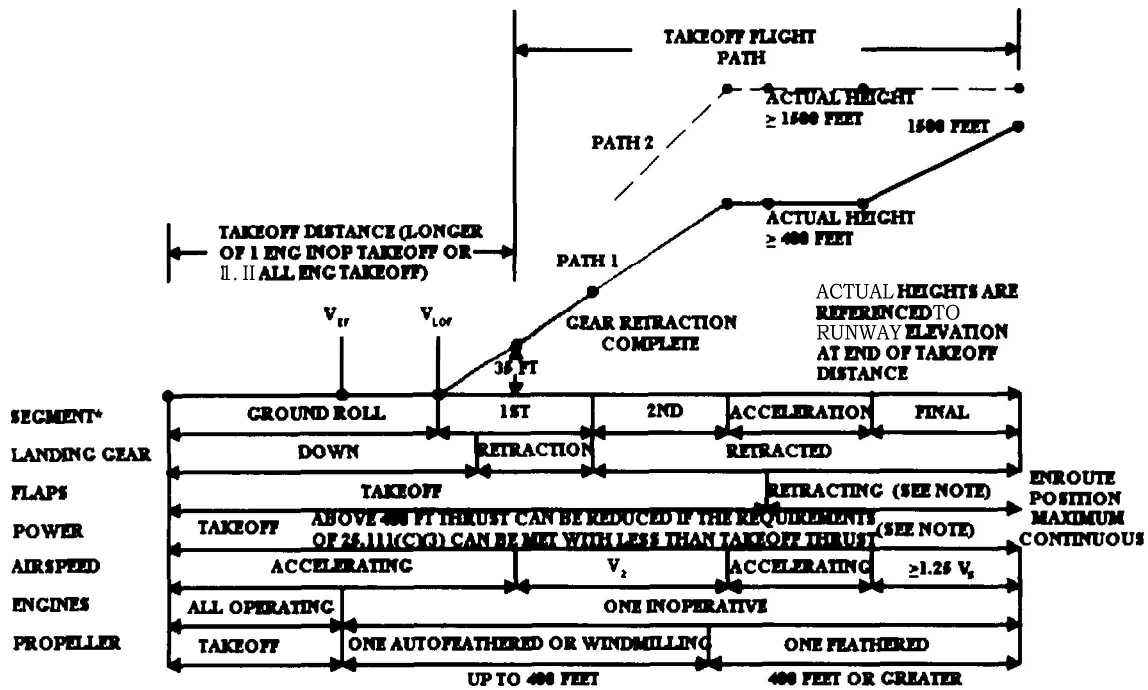
* a. Takeoff Flight Path - § 25.115(a).

(1) Explanation. The takeoff flight path begins at the end of the takeoff distance and at a height of 35 ft. above the takeoff surface, and ends when the airplane's actual height is the higher of 1,500 ft. above the takeoff surface or at an altitude at which the configuration and speed have been achieved where the requirements of § 25.121(c) can be met. (See paragraph 12 of this AC (§ 25.111) for additional discussion.) Section 25.115(a) states that the takeoff shall be considered to begin at a height of 35 feet, recognizing that in the case of a wet runway the *

*airplane will only be at a height of 15 feet. For takeoffs from wet runways, the actual airplane height will be 20 feet lower than the takeoff flight path determined under § 25.115. Therefore, the airplane will be 20 feet closer vertically to obstacles after taking off from a wet runway compared to taking off from a dry runway. *

(2) Procedures.

FIGURE 14- 1. TAKEOFF SEGMENTS & NOMENCLATURE



Note: The final takeoff segment will usually begin with the airplane in the en route configuration and with maximum continuous thrust, but it is not required that these conditions exist until the end of the takeoff path when compliance with § 25.121(c) is shown. The time limit on takeoff' thrust cannot be exceeded.

* Segments as defined by § 25.121.

b. Net Takeoff Flight Path - §§ 25.115(b) and (c).

(1) Explanation.

(i) The net takeoff flight path is the actual flight path diminished by a gradient of 0.8 percent for two-engine airplanes, 0.9 percent for three-engine airplanes, and 1.0 percent for four-engine airplanes.

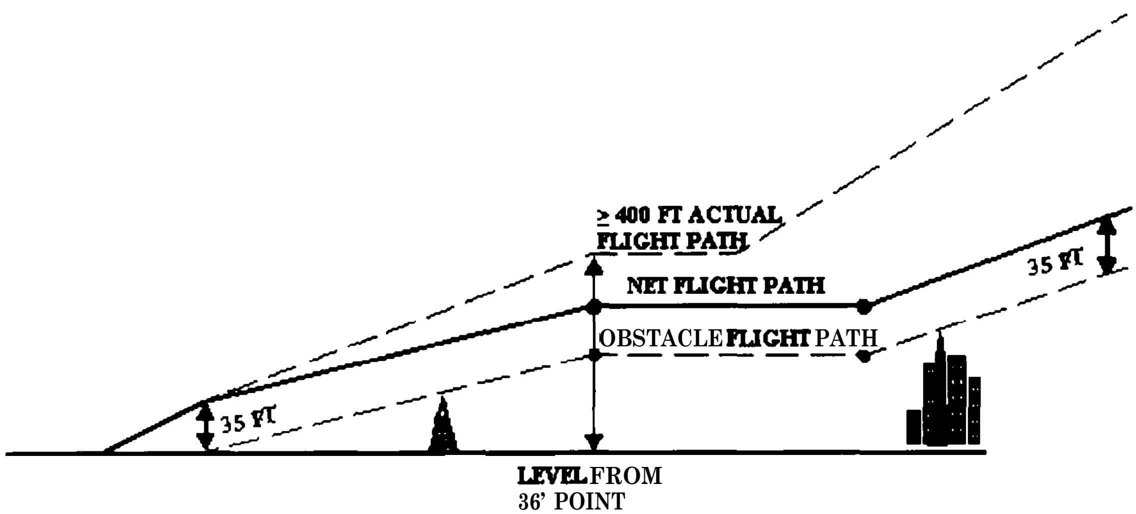
(ii) For the level flight acceleration segment, these prescribed gradient reductions may be applied as an equivalent reduction in acceleration in lieu of reduction in net flight path. (See paragraph 12 (ref. § 25.111) of this AC for additional discussion.)

(iii) SR-422B, and § 121.189(d), require that no airplane may take off at a weight in excess of that shown in the AFM to correspond with a net takeoff flight path that clears all obstacles either by at least a height of 35 A. vertically, or by at least 200 A. horizontally within the airport boundaries, and by at least 300 A. horizontally after passing beyond the boundaries.

(iv) With turns in the net takeoff flight path, obstacle clearance determination requires consideration of both radius of turn and climb gradient decrement. Radius of turn, for use in obstacle lateral separation, is not airplane dependent and is readily calculated from speed and bank angle. Climb gradient decrements, however, are airplane dependent. Climb gradient decrements for bank angles up to at least 15 degrees should be contained in the AFM.

(2) Procedures.

FIGURE 14-2. NET TAKEOFF FLIGHT PATH



15. CLIMB: GENERAL - § 25.117.

a. Explanation. This section states the climb requirements of §§ 25.119 and 25.12 1 must be complied with at each weight, altitude, and ambient temperature within the operational limits established for the airplane and with the most unfavorable center of gravity for each configuration. When approval of an airplane for operation in known icing conditions is requested, compliance with the approach climb requirements of § 25.121(d), and landing climb requirements of § 25.119, should be demonstrated with residual ice accretions on unprotected areas of the airframe. For further guidance on this subject see paragraph 23 1, “Performance Requirements for Flight in Icing Conditions,” in Chapter 8 of this AC.

b. Procedures. None.

16. LANDING CLIMB: ALL-ENGINES-OPERATING - § 25.119.

a. Explanation. Section 25.119(a) states that the engines are to be set at the power or thrust that is available 8 seconds after initiating movement of the power or thrust controls from the minimum flight idle position to the go-around power or thrust setting. The procedures given below are for the determination of this maximum thrust for showing compliance with the climb requirements of § 25.119.

b. Procedures.

(1) The engines should be trimmed to the low side of the idle trim band, if applicable, as defined in the airplane maintenance manual. The effect of any variation in the idle fuel flow schedule for engines with electronic fuel controllers is typically negligible (but any such claim should be adequately substantiated).

(2) At the most adverse test altitude, not to exceed the maximum field elevation for which certification is sought plus 1,500 A., and with the most adverse bleed configuration expected in normal operations, stabilize the airplane in level flight with symmetrical power on all engines, landing gear down, flaps in the landing position, at a speed of 1.3 V_{S0}. Retard the throttle(s) of the test engine(s) to flight idle and determine the time needed to reach a stabilized r.p.m., as defined below, for the test engine(s) while maintaining level flight or the minimum rate of descent obtainable with the thrust of the remaining engine(s) not greater than maximum continuous thrust (MCT). Engine flight idle r.p.m. is considered to be stabilized when the initial rapid deceleration of all rotors is completed. This has usually been 8-20 seconds. This can be determined in the cockpit as the point where rapid movement of the tachometer ceases. For some airplanes it may be desirable to determine the deceleration time from plots of r.p.m. versus time.

(3) For the critical air bleed configuration, stabilize the airplane in level flight with symmetric power on all engines, landing gear down, flaps in the landing position, at a speed of 1.3 V_{S0}, simulating the estimated minimum climb-limited landing weights (goal is low airspeed for low idle r.p.m.) at an altitude sufficiently above the selected test altitude so that time to descend to the test altitude with the throttles closed equals the appropriate engine r.p.m. stabilization time determined in paragraph (2) above. Retard the throttles to the flight idle position and descend at 1.3 V_{S0} to approximately the test altitude. When the appropriate time has elapsed, rapidly advance the power or thrust controls to the go-around power or thrust setting. The power or thrust controls may first be advanced to the forward stop and then retarded to the go-around power or thrust setting. At the applicant's option, additional less critical bleed configurations may be tested.

(4) The thrust that is available 8 seconds after the initiation of movement of the power or thrust controls from the minimum flight idle position, in accordance with paragraph (3) above, will be the maximum permitted for showing compliance with the landing climb requirements of § 25.119(a), and Section 4T. 119(a) of SR-422B (see Appendix 1) for each of the bleed combinations tested in accordance with paragraph (3) above. If AFM performance is presented

such that there is no accountability for various bleed conditions, the thrust obtained with the most critical airbleed shall be used for landing climb performance for all operations. The effects of anti-ice bleed must be accounted for.

17. CLIMB: ONE-ENGINE-INOPERATIVE - § 25.121.

a. Explanation. None.

b. Procedures.

(1) Two methods for establishing one-engine-inoperative climb performance follow:

(i) Reciprocal heading climbs are conducted at several thrust-to-weight conditions from which the performance for the AFM is extracted. These climbs are flown with the wings nominally level. Reciprocal climbs may not be necessary if inertial corrections (or another equivalent means) are applied to account for wind gradients.

(ii) Drag polar-s and one-engine-inoperative yaw drag data are obtained for expansion into AFM climb performance. These data are obtained with the wings nominally level. Reciprocal heading check climbs are conducted to verify the predicted climb performance. These check climbs may be flown with the wings maintained in a near level attitude. Reciprocal climbs may not be necessary if inertial corrections (or another equivalent means) are applied to account for wind gradients.

(2) If full rudder with wings level cannot maintain constant heading, small bank angles into the operating engine(s), with full rudder, should be used to maintain constant heading. Unless the landing lights automatically retract with engine failure, testing should be conducted with the lights extended for § 25.121(a) Takeoff; landing gear extended, § 25.121(b) Takeoff; landing gear retracted, and § 25.12 1 (d) Approach.

(3) The climb performance tests with landing gear extended, in accordance with § 25.121 (a), may be conducted with the landing gear and gear doors in the position they finally achieve after “gear down” selection. The critical configuration for the landing gear extended climb is considered to be that which presents the largest frontal area to the local airflow. This would normally be with no weight on the landing gear (full strut extension and trucks tilted) and all gear doors open. However, since the takeoff path will be determined by measurement of continuous takeoffs, or checked by continuous takeoffs if constructed by the segmental method (Ref. § 25.111 (d)), any non-conservatism arising from the gear doors “closed” climb data will be evident. Also, some measure of conservatism is added to the landing gear extended climb performance by the requirement of § 25.111 (d)(3) for the takeoff path data to be based on the airplane’s performance without ground effect.

(4) If means, such as variable intake doors, are provided to control powerplant cooling air supply during takeoff, climb, and en route flight, they should be set in a position that will maintain the temperature of major powerplant components, engine fluids, etc., within the

established limits. The effect of these procedures should be included in the climb performance of the airplane. These provisions apply for all ambient temperatures up to the highest operational temperature limit for which approval is desired. (Reference: § 25.1043)

(5) The latter parts of §§ 25.12 l(a)(1) and (b)(l), which state "...unless there is a more critical power operating condition existing later along the flight path..." are intended to cover those cases similar to where a wet engine depletes its water and reverts to dry engine operation. This is not intended to cover normal altitude thrust lapse rates above the point where the landing gear is fully retracted. (Reference: Preamble to SR-422A)

(6) Section 25.12 l(d) requires that the stalling speed for the approach configuration, landing gear retracted, not exceed 110 percent of the stalling speed for the related landing configuration, landing gear extended. This stall speed ratio requirement is to ensure that an adequate margin above the stall speed in the selected approach configuration is maintained during flap retraction. To achieve this stall speed spread requirement, it is permissible to arbitrarily increase the landing flap stalling speed, V_{S0}, to show compliance. The AFM must, however, base the landing speed on the increased stalling speed, and the landing distance demonstrations and the AFM landing field length requirements must also be predicated on the increased speed. The stall warning requirements of § 25.207 must be established for the adjusted stalling speed. However, the § 25.203 stall characteristics requirements must still be met at the normal stall speed. (An alternative to raising the landing flap stall speed, V_{S0}, is to simply increase the landing speed stall ratio to a value greater than 1.3.)

18. EN ROUTE FLIGHT PATHS - § 25.123.

a. Explanation. This guidance is intended for showing compliance with the requirements of § 25.123 and application to the operating requirements of §§ 12 1.191 and 12 1.193, which specify the clearances over terrain and obstructions required of the net en route flight paths subsequent to the failure of one or two engines.

b. Procedures.

(1) Sufficient en route climb performance data should be presented in the AFM to permit the determination of the net climb gradient and the net flight path in accordance with §§ 25.123(b) and (c) for all gross weights, altitudes, and ambient temperatures within the operating limits of the airplane. This en route climb performance data should be presented for altitudes up to the all-engines-operating ceiling to permit the calculation of drift-down data in the event of an en route engine failure.

(2) Fuel Consumption Accountability. The effect of the variation of the airplane's weight along the flight path due to the progressive consumption of fuel may be taken into account using fuel flow rates obtained from airplane manufacturers' test data. If measured fuel flow data is unavailable, a conservative fuel flow rate not greater than 80 percent of the engine specification flow rate at maximum continuous thrust (MCT) may be used.

(3) The procedures and flight conditions upon which the en route flight path data are based should be provided to the flightcrew. Credit for fuel dumping, if available and included in the flightcrew procedures, may be used to achieve the performance capability presented in the AFM. A conservative analysis should be used in taking into account the ambient conditions of temperature and wind existing along the flight path. All performance should be based on the net flight path and with MCT on the operating engine(s).

19. LANDING - $25.125.

a. Explanation.

(1) The landing distance is the horizontal distance from the point at which the main gear of the airplane is 50 A. above the landing surface (treated as a horizontal plane through the touchdown point) to the point at which the airplane is brought to a stop. (For water landings, a speed of approximately 3 knots is considered "stopped.") In this AC, the distance is treated in two parts: the airborne distance from 50 A. to touchdown, and the ground distance from touchdown to stop. The latter may be further subdivided into a transition phase and a full braking phase if the applicant prefers this method of analysis.

(2) The term V_{REF} used in this AC means the landing threshold speed (i.e., speed at 50 A. height) scheduled in the AFM for normal operations. The minimum value of V_{REF} is specified in § 25.125(a)(2) as $1.3V_S$, which provides an adequate margin above the stall speed to allow for likely speed variations during an approach in low turbulence. If the landing demonstrations are unable to show the acceptability of the minimum approach speed, and the tests are predicated on the use of a V_{REF} greater than the minimum 1.3 V,, the landing distance data presented in the AFM must be based upon the higher approach speed.

(3) The engines should be set to the high side of the flight idle trim band, if applicable, for the landing flight tests. The effect of any variation in the idle fuel flow schedule for engines with electronic fuel controllers is typically negligible (but any such claim should be adequately substantiated).

b. Procedures for Determination of the Airborne Distance. Three acceptable means of compliance are described in paragraphs (1), (2), and (3) below. These differ from the "traditional" method in which steep approaches and high touchdown sink rates were permitted. Such a demonstration of maximum performance is no longer considered acceptable. However, the distances obtained using that method have resulted in a satisfactory operational safety record. The methods given here allow credit for the amount of testing an applicant is prepared to conduct, such that if the method described in paragraph 19b(3) (the most complex) is chosen, distances typical of those from the "traditional" method should be obtained, but without incurring the associated risks during testing.

NOTE. If it is determined that the constraints on approach angle and touchdown rate-of-sink described in paragraphs (2) and (3), below, are not appropriate due to novel or unusual features of future transport category airplane design, new criteria may be established. Such a change would be acceptable only if it is determined that an equivalent level of safety to existing performance standards and operational procedures is maintained.

(1) Experience shows an upper bound to the Part 25 zero-wind airborne distances achieved in past certifications and, similarly, a minimum speed loss. These are approximated by the following:

$$\text{Air Distance (feet)} = 1.55\,(V_{REF}-80)^{1.35}+800 \quad \text{where } V_{REF} \text{ is in knots TAS}$$

$$\text{Touchdown Speed} = V_{REF}-3 \text{ knots}$$

An applicant may choose to use these relationships to establish landing distance in lieu of measuring airborne distance and speed loss. If an applicant chooses to use these relationships, it must be shown by test or analysis that they do not result in air distances or touchdown speeds that are nonconservative.

(2) If an applicant chooses to measure airborne distance or time, at least six tests covering the landing weight range are required for each airplane configuration for which certification is desired. These tests should meet the following criteria:

(i) A stabilized approach, targeting a glideslope of -3 degrees and an indicated airspeed of V_{REF}, should be maintained for a sufficient time prior to reaching a height of 50 feet above the landing surface to simulate a continuous approach at this speed. During this time, there should be no appreciable change in the power setting, pitch attitude, or rate of descent. The average glideslope of all landings used to show compliance should not be steeper than -3 degrees.

(ii) Below 50 feet, there should be no nose depression by use of the longitudinal control and no change in configuration, except for reduction in power.

(iii) The target rate of descent at touchdown should not exceed 6 feet per second. Target values cannot be achieved precisely; however, the average touchdown rate of descent should not exceed 6 feet per second.

(3) If the applicant conducts enough tests to allow a parametric analysis (or equivalent method) that establishes, with sufficient confidence, the relationship between airborne distance (or time) as a function of the rates of descent at 50 feet and touchdown, the 14 CFR part 25 airborne distances may be based on an approach angle of -3.5 degrees, and a touchdown sink rate of 8 feet per second (see paragraph 19g for a sample of this analysis method).

(i) The air distance or air time established by this method may not be less than 90 percent of the lowest demonstrated value obtained using the target values for approach angle and touchdown sink rate specified in paragraph (ii), below. Test data with approach angles steeper than -3.5 degrees, or touchdown sink rates greater than 8 feet per second, may not be used to satisfy this requirement.

(ii) In order to determine the parametric relationships, it is recommended that test targets should span approach angles from -2.5 degrees to -3.5 degrees, and sink rates at touchdown from 2-6 ft. per second. Target speed for all tests should be V_{REF}.

(iii) Below 50 feet, there should be no nose depression by use of the longitudinal control and no change in configuration that requires action by the pilot, except for reduction in power.

(iv) If an acceptable method of analysis is developed by an applicant to statistically establish a satisfactory confidence level for the resulting parametric relationships, then 12 tests, in each aerodynamic configuration for which certification is desired, will be sufficient. More tests will be necessary if the distribution of the data does not give sufficient confidence in the parametric correlation. Past experience has shown that a total of 40 landings would establish a satisfactory confidence level without further analysis. Autolands may be included in the analysis but should not comprise more than half of the data points. If it is apparent that configuration is not a significant variable, all data may be included in a single parametric analysis.

(v) If an applicant proposes any other method as being equivalent to a parametric analysis, that method should be based on a developed mathematical model that employs performance-related variables such as thrust, attitude, angle of attack, and load factor to adequately reproduce the flight test trajectory and airspeed variation from the 50 foot point to touchdown. Such a mathematical model should be validated by not less than 12 tests in each aerodynamic configuration for which certification is desired, and be justified by a comparison of tested and calculated landing airborne distances.

(vi) For the same aerodynamic configuration as previously certificated--if new tests are necessary to substantiate performance to a weight higher than that permitted by the extrapolation limits of § 25.21(d), two landings per configuration will be required for each 5 percent increase in landing weight, with a maximum total requirement of six landings. These may be merged with previous certification tests for parametric analysis, whether the previous certification was conducted by this method or not. If a new aerodynamic configuration is proposed, the 12 tests per configuration described in paragraph (iv), above, must be conducted.

(vii) In calculating the AFM landing distances, the speed loss from 50 feet to touchdown, as a percentage of V_{REF}, may be determined using the conditions described in paragraph 19b(3).

(4) <u>Whichever method is chosen</u> to establish airborne distances, satisfactory flight characteristics must be demonstrated in the flare maneuver when a final approach speed of V_{REF}-5 knots is maintained down to 50 feet.

(i) Below 50 feet, the application of longitudinal control to initiate flare should occur at the same altitude as for a normal “on-speed” landing; no nose depression should be made and power should not be increased to facilitate the flare.

(ii) All power levers should be in their minimum flight idle position prior to touchdown.

(iii) The normal flare technique should be used such that the touchdown speed should be at least 5 knots less than the touchdown speed used to establish the landing distance and the rate of descent at touchdown should not be greater than 6 feet per second.

(iv) This demonstration must be performed at both maximum landing weight and near minimum landing weight.

(v) These VREF-5 knots landing demonstration must not require the use of high control forces or full control deflections.

c. Procedures for Determination of the Transition and Stopping Distances,

(1) The transition distance extends from the initial touchdown point to the point where all approved deceleration devices are operative. The stopping distance extends from the end of transition to the point where the airplane is stopped. The two phases may be combined if the applicant prefers this method of analysis.

(2) If sufficient data are not available, there should be a minimum of six landings in the primary landing configuration. Experience has shown that if sufficient data are available for the airplane model to account for variation of braking performance with weight, lift, drag, ground speed, torque limit, etc., at least two test runs are necessary for each configuration when correlation for multiple configurations is being shown.

(3) A series of at least six measured landing tests covering the landing weight range should be conducted on the same set of wheels, tires, and brakes in order to substantiate that excessive wear of wheel brakes and tires is not produced in accordance with the provisions of § 25.125(b). The landing tests should be conducted with the normal operating brake pressures for which the applicant desires approval. The main gear tire pressure should be set to not less than the maximum pressure desired for certification corresponding to the specific test weight. Longitudinal control and brake application procedures must be such that they can be consistently applied in a manner that permits the airplane to be de-rotated at a controlled rate to preclude an excessive nose gear touchdown rate and so that the requirements of §§ 25.125(a)(4) and (5) are met. Nose gear touchdown rates in the certification landing tests should not be greater than eight feet per second. Certification practice has not allowed manually applied brakes before all main gear wheels are firmly on the ground.

(4) Airplane operating procedures appropriate for determination of landing distance must be described in the performance section of the AFM.

(5) Propeller pitch position used in determining the normal all-engines-operating landing stopping distance should be established using the criteria of § 25.125(f) for those

airplanes that may derive some deceleration benefit from operating engines. Section 25.125(f) states that if the landing distance determined using a "device" that depends on the operation of any engine would be "noticeably increased" when a landing is made with that engine inoperative, the landing distance must be determined with that engine inoperative, unless a "compensating means" will result in one-engine-inoperative landing distances not greater than those with all engines operating. Acceptable interpretations of the terms "device," "noticeably increased," and "compensating means" are described below.

(i) If the propeller produces drag at any speed during the stopping phase of the normal all-engines-operating landing distance, the maximum drag from this "device" for which performance credit may be taken is that which results from a propeller pitch position that renders zero thrust at zero airspeed. If the normal operational ground idle setting produces negative thrust at zero airspeed, the all-engines-operating stopping distances should be determined using a special flight test power lever stop to limit the propeller blade angle.

(ii) Distances should be measured for landings made with the propeller feathered on one engine, and ground idle selected after touchdown on the operating engines. The airplane configuration for this test, including the ground idle power lever position, should be the same as that used for the all-engines-operating landing distance determination. The nose wheel should be free to caster, as in V_{MCG} tests, to simulate wet runway surface conditions. Differential braking may be used to maintain directional control. This testing should be conducted at a minimum of three weights that cover the expected range of operational landing weights. If the resulting distances do not exceed the all-engines-operating landing distances by more than two percent (2%), they are not "noticeably increased" and no further testing is required to take performance credit for all-engines-operating disking drag in Airplane Flight Manual (AFM) landing distances.

(iii) If the distances determined in paragraph (ii), above, are more than two percent greater than the all-engines-operating landing distances, it must be shown that a "compensating means" exists in order to take performance credit for the all-engines-operating disking drag. Reverse propeller thrust on the operating engines is considered a "compensating means" if the resulting landing distances, with one propeller feathered, are demonstrated to be not longer than those determined for all-engines-operating with disking drag. The airplane configuration for this test should be the same as that used for the all-engines-operating landing distance determination. The nose wheel should be free to caster, as in V_{MCG} tests, to simulate wet runway surface conditions. Differential braking may be used to maintain directional control. Reverse thrust should not be selected until one second after nose wheel touchdown. This testing should be conducted at a minimum of three weights that cover the expected range of operational landing weights.

d. Instrumentation and Data. Instrumentation should include a means to record the airplane's glide path relative to the ground, and the ground roll against time, in a manner that permits determining the horizontal and vertical distance time-histories. The appropriate data to permit analysis of these time-histories should also be recorded.

e. Landing on Unpaved Runways. Guidance material for evaluation of landing on unpaved runways is contained in Chapter 8 of this AC.

f. Automatic Braking Systems. Guidance material relative to evaluation of auto-brake systems is provided in paragraph 55c(6) of this AC.

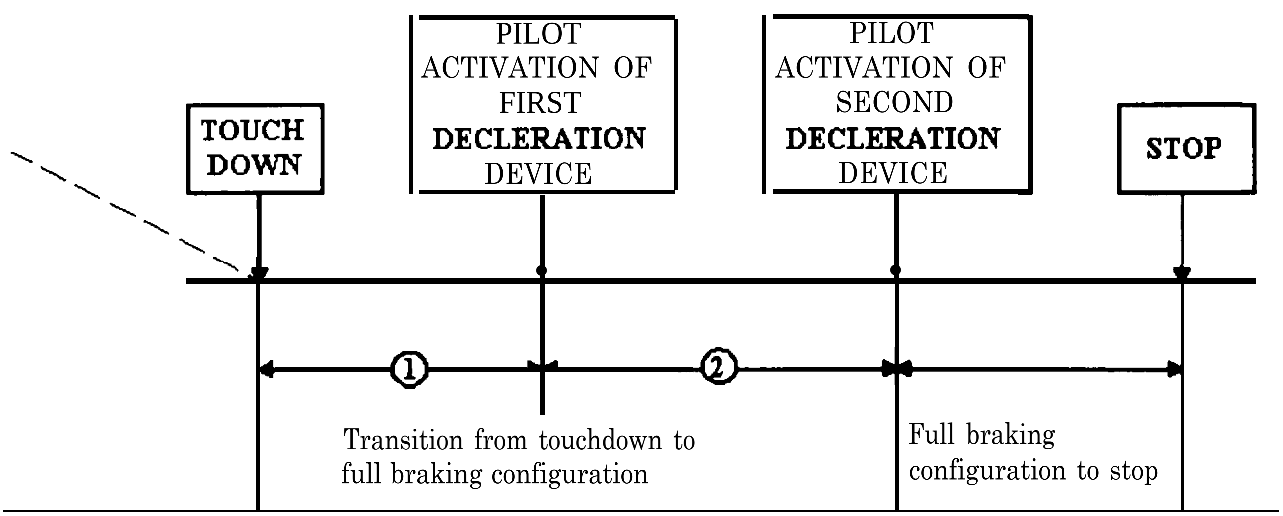
g. Airplane Flight Manual Landing Distances.

(1) As a minimum, the AFM must include data for standard temperature and zero runway gradient showing the variation of landing distance with weight (up to maximum takeoff weight), altitude, and wind. If the airplane is intended for operation under Part 12 1 of the FAR, the distances presented should include the operational field length factors for both dry and wet runways required by § 12 1.195.

* (2) In accordance with § 25.101(i), AFM landing distances must be determined with all the airplane wheel brake assemblies at the fully worn limit of their allowable wear range. The brakes may be in any wear state during the flight tests used to determine the landing distances, as long as a suitable combination of airplane and dynamometer tests is used to determine the landing distances corresponding to fully worn brakes. Alternatively, the relationship between brake wear and stopping performance established during accelerate-stop testing may be used if it encompasses the brake wear conditions and energies achieved during the airplane flight tests used to establish the landing distances. *

(3) In deriving the scheduled distances, the time delays shown below should be assumed.

FIGURE 19- 1. LANDING TIME DELAYS



(i) ① This segment represents the flight test measured average time from touchdown to pilot activation of the first deceleration device. For AFM data expansion, use the longer of 1 second or the test time.

(ii) 2 This segment represents the flight test measured average test time from pilot activation of the first deceleration device to pilot activation of the second deceleration device. For AFM data expansion, use the longer of 1 second or the test time.

(iii) Step 2 is repeated until pilot activation of all deceleration devices has been completed and the airplane is in the full braking configuration.

(4) <u>For approved automatic deceleration devices</u> (e.g., autobrakes or auto-spoilers, etc.) for which performance credit is sought for AFM data expansion, established times determined during certification testing may be used without the application of the 1 -second minimum time delay required in the appropriate segment above.

(5) <u>It has been considered acceptable</u> to expand the airborne portion of the landing distance in terms of a fixed airborne time, independent of airplane weight or approach speed.

(6) <u>Assumptions to be made</u> in assessing the effect of wind on landing distance are discussed in paragraph 3 of this AC.

h. <u>Parametric Analysis Data Reduction</u>. The following is an acceptable method of converting the test data to a mathematical model for the parametric analysis method of air distance described in paragraph 19b(3).

Test Data for Each Test Point:

R/S_{50} = Rate of sink at 50 ft. above landing surface, Ft/Sec
R/S_{TD} = Rate of sink at touchdown, Ft/Sec
V_{50} = True airspeed at 50 ft. above landing surface, Ft/Sec
V_{TD}= True airspeed at touchdown, Ft/Sec
t = Air time 50 A. to touchdown, Sec

The multiple linear regression analysis as outlined below is used to solve for the constant of the two independent variable equations:

$$50/t = a + b(R/S_{50}) + (c)(R/S,,)$$

To maintain the same units for all variables, the dependent variable is chosen as 50/t.

The test values of all the test points, 1 through n, are processed as follows, where n equals the number of test points and R1 through R13 are the regression coefficients:

$$R1 = \sum_1^n R/S_{50}$$

$$R2 = \sum_1^n (R/S_{50})^2$$

$R3 = \sum_1^n R/S_{TD}$

$R4 = \sum_1^n (R/S_{TD})^2$

$R5 = \sum_1^n (R/S_{50})(R/S_{TD})$

$R6 = \sum_1^n (50/t)$

$R7 = \sum_1^n (R/S_{50})(50/t)$

$R8 = \sum_1^n (R/S_{TD})(50/t)$

$R9 = (n)(R2)-(R1)^2$

$R10 = (n)(R8)-(R3)(R6)$

$R11 = (n)(R5)-(R1)(R3)$

$R12 = (n)(R7)-(R1)(R6)$

$R13 = (n)(R4)-(R3)^2$

$c = ((R9)(R10)-(R11)(R12))/((R9)(R13)-(R11)^2)$

$b = ((R12)-(c)(R11))/R9$

$a = ((R6)-(b)(R1)-(c)(R3))/n$

In the same manner, determine the values of the constants, a, b, and c, in an equation for speed reduction between 50 ft. and touchdown by replacing 50/t with (V_{50}/V_{TD}) for each test run.

After determining the values of the constants, the two equations are used to calculate the time from 50 ft. to touchdown and V_{50}/V_{TD} for the desired conditions of -3.5 degrees flight path and R/S_{TD} = 8 ft/Sec. The R/S_{50} is calculated from the approach path and V_{50}.

After V_{TD} is determined, the air distance may be determined for the average flare speed and t.

Example:

Test Data:

Run	R/S_{50}	R/S_{TD}	V_{50}	V_{TD}	t
1	13.4	6.1	219	214	5.6
2	10.9	1.8	223	218	8.5
3	7.9	5.8	209	201	7.4
4	8.3	2.3	213	206	9.6
5	9.8	4.1	218	212	7.5

Results:

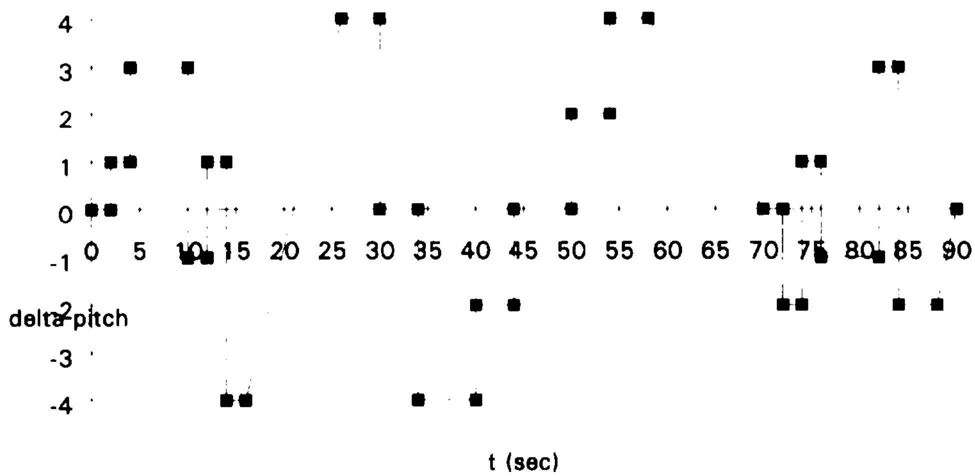
$50/t = 1.0432 + .3647(R/S_{50}) + .4917(R/S_{TD})$

$V_{50}/V_{TD} = 1.05508 - .003198(R/S_{50}) + .001684(R/S_{TD})$

For conditions of $V_{50} = 220$, flight path = -3.5 degrees, $R/S_{TD} = 8.0$, the resultants are:

R/s,, = 13.43 $V_{50}/V_{TD} = 1.0256$
t = 5.063 sec.Air Distance = 1100 A.

FIGURE 20-l. SAMPLE PITCH TRACKING TASK



(6) A-PC Assessment Criteria.

* (i) The evaluation of an airplane for A-PC susceptibility will be conducted using the FAA Handling Qualities Rating Method (HQRM). Tasks should be designed to focus on any A-PC tendencies that may exist. Figure 20-2 contains the descriptive material associated with A-PC characteristics and its relationship to the PIO Rating Scale called out in the U.S. Military Standard.

(ii) Figure 20-2 provides the FAA Handling Qualities Rating descriptions of airplane motions that may be seen during the conduct of specific A-PC tasks or during tests throughout the entire certification flight test program. *The italicized* phrases highlight major differences between rating categories in the table. *

* FIGURE 20-2. A-PC RATING CRITERIA AND COMPARISON TO MIL STANDARD

FAA HQ RATING	A-PC CHARACTERISTICS DESCRIPTION	MIL 1797A STD. PIO RATING SCALE
SAT	NO TENDENCY FOR PILOT TO INDUCE UNDESIRABLE MOTION.	1
	UNDESIRABLE MOTIONS (OVERSHOOTS) *TEND TO OCCUR* WHEN PILOT INITIATES ABRUPT MANEUVERS OR ATTEMPTS TIGHT CONTROL. THESE MOTIONS CAN BE PREVENTED OR ELIMINATED BY PILOT TECHNIQUE. (NO MORE *THAN MINIMAL PILOT COMPENSATION REQUIRED)*	2
ADQ	UNDESIRABLE MOTIONS (UNPREDICTABILITY OR OVER CONTROL) *EASILY INDUCED* WHEN PILOT INITIATES ABRUPT MANEUVERS OR ATTEMPTS TIGHT CONTROL. THESE MOTIONS CAN BE PREVENTED OR ELIMINATED BUT ONLY AT SACRIFICE TO TASK PERFORMANCE OR THROUGH *CONSIDERABLE* PILOT ATTENTION AND EFFORT. (NO MORE *THAN EXTENSIVE PILOT COMPENSATION REQUIRED)*	3
CON	*OSCILLATIONS TEND TO DEVELOP* WHEN PILOT INITIATES ABRUPT MANEUVERS OR ATTEMPTS TIGHT CONTROL. ADEQUATE PERFORMANCE IS NOT ATTAINABLE AND PILOT MUST REDUCE GAIN TO RECOVER. (PILOT CAN RECOVER BY MERELY REDUCING GAIN)	4
UNSAT	*DIVERGENT OSCILLATIONS* TEND TO DEVELOP WHEN PILOT INITIATES *ABRUPT MANEUVERS* OR ATTEMPTS TIGHT CONTROL. PILOT MUST OPEN LOOP BY RELEASING OR FREEZING THE CONTROLLER.	5
	DISTURBANCE OR *NORMAL PILOT CONTROL* MAY CAUSE DIVERGENT OSCILLATION. PILOT MUST OPEN CONTROL LOOP BY RELEASING OR FREEZING THE CONTROLLER.	6

*

SAT = Satisfactory
ADQ = Adequate
CON = Controllable
UNSAT = Unsatisfactory or Failed

* (iii) The required H.Q. rating for A-PC tendencies is shown in Figure 12 of Appendix 7. As described in that appendix, the minimum H.Q. rating, and consequently the pass/fail criteria, varies with the flight envelope, atmospheric disturbance considered, and failure state. For example, Figure 20-3 below shows a handling qualities matrix for a tracking task with the airplane at aft c.g. trimmed in flight conditions giving 1.3 g to buffet onset. *

FIGURE 20-3

EXAMPLE OF MINIMUM PERMITTED HQ RATING FOR A-PC TENDENCIES

Airplane at aft c.g. trimmed in conditions giving 1.3 g to buffet onset

AIRSPEED	M_{LRC}	M_{LRC}	M_{LRC}	M_{LRC}
LOAD FACTOR RANGE	0.8 TO 1.3	-1.0 TO 2.5	0.8 TO 1.3	-1.0 TO 2.5
BUFFET LEVEL	ONSET	DETERRENT	ONSET	DETERRENT
TURBULENCE	LIGHT	LIGHT	LIGHT	LIGHT
FAILURE	NONE	NONE	IMPROBABLE FAILURE OF SAS	IMPROBABLE FAILURE OF SAS
FLIGHT ENVELOPE	NFE	LFE	NFE	LFE
MINIMUM PERMITTED HQ RATING	SAT	ADQ	ADQ	CON

SAT = Satisfactory ADQ = Adequate CON = Controllable

NFE = Normal flight envelope LFE = Limit flight envelope

SAS = Stability augmentation system

M_{LRC} = Long range cruise mach number

e. Tailplane stall investigation with ice accretion.

(1) Configuration:

(i) All normal combinations of wing flaps and landing gear, except the cruise configuration.

(ii) Critical weight and c.g. for the test wing flap and landing gear position.

(iii) Speeds from $1.2V_S$ or V_{REF}-5 kts, as appropriate to the wing flap position, up to the maximum speed to be encountered operationally in a given flap/gear configuration that will not result in exceeding V_{FE} or V_{LE}, as applicable, during the recovery.

(iv) Power or thrust: Flight idle to maximum takeoff.

(v) Icing condition: The applicant should specify the critical ice case(s) to be investigated in terms of location, shape, thickness, and texture. FAA concurrence on the critical ice shape(s) should be obtained prior to testing. The critical ice case(s) should include an allowance for any time delays in activation of the ice protection system associated with ice detection or observation systems, or that may be reasonably expected in service. If ice accretion on the wings can result in increased airflow angle of attack on the horizontal tail, ice shapes will also be required on the wing surface, and should be representative of the ice accumulation that would normally be expected in the icing condition defined to be critical for the tailplane. It should be noted that ice accreted with the flaps retracted may result in a more critical condition than ice accreted with the flaps extended. Ice accretion thickness need not be greater than that resulting from flight in the maximum continuous atmospheric icing conditions defined in Appendix C to Part 25.

(2) Zero g Pushover Maneuver: The test procedure described below is essentially a nose down pitching maneuver. Execution of this maneuver should be preceded by experimentation to determine initial entry speeds and pitch attitudes that will result in the airplane achieving the target load factor and airspeed as it pitches through approximately level flight.

(i) Trim the airplane in the test configurations and at the test speeds prescribed in paragraph 20e(1), above.

(ii) Initial testing should be conducted by moving the control column forward at a slow rate while evaluating for force lightening or force reversal. Continue the test by incrementally increasing the rate of control movement until a zero g flight condition is obtained or, if limited by elevator power, to the lowest load factor attainable.

WARNING: The test maneuver described above may result in a sudden and violent loss of pitch stability or control due to aerodynamic stall of the horizontal stabilizer and/or elevators. High stick forces may be required to effect recovery; consequently, the non-flying pilot should be prepared to immediately retract the flaps and lend assistance in overcoming any high nose down stick forces.

(iii) A push longitudinal control force must be required throughout the test maneuver.

(iv) The airplane should demonstrate suitable controllability and maneuverability throughout the maneuver with no force reversal and no tendency to diverge in pitch.

(3) Steady State Sideslip Maneuver: The following test procedure is intended to determine if the airplane is susceptible to tailplane stall resulting from detached flow on the horizontal tail as induced by a lateral flow component.

(i) For the test conditions described in paragraph 20e(1), establish the airplane in a straight, steady sideslip, up to the sideslip angle appropriate to normal operation of the airplane as used to demonstrate compliance with § 25.177(c).

(ii) Changes in longitudinal control force to maintain speed with increasing sideslip should be progressive with no reversals or sudden discontinuities.

f. Maneuvering Characteristics - § 25.143(f).

(1) General. An acceptable means of compliance with the requirement that stick forces may not be excessive when maneuvering the airplane is to demonstrate that, in a turn for 0.5g incremental normal acceleration (0.3g above 20,000 feet) at speeds up to V_{FC}/M_{FC}, the average stick force gradient does not exceed 120 pounds per g.

(2) Interpretive Material.

(i) The objective of § 25.143 is to ensure that the limit strength of any critical component on the airplane would not be exceeded in maneuvering flight. In much of the structure, the load sustained in maneuvering flight can be assumed to be directly proportional to the load factor applied. However, this may not be the case for some parts of the structure (e.g., the tail and rear fuselage). Nevertheless, it is accepted that the airplane load factor will be a sufficient guide to the possibility of exceeding limit strength on any critical component if a structural investigation is undertaken whenever the design positive limit maneuvering load factor is closely approached. If flight testing indicates that the positive design limit maneuvering load factor could be exceeded in steady maneuvering flight with a 50 pound stick force, the airplane structure should be evaluated for the anticipated load at a 50 pound stick force. The airplane will be considered to have been overstressed if limit strength has been exceeded in any critical component. For the purposes of this evaluation, limit strength is defined as the lesser of either the limit design loads envelope increased by the available margins of safety, or the ultimate static test strength divided by 1.5.

(ii) Minimum Stick Force to Reach Limit Strength.

(A) A stick force of at least 50 pounds to reach limit strength in steady maneuver or wind-up turns is considered acceptable to demonstrate adequate minimum force at limit strength in the absence of deterrent buffeting. If heavy buffeting occurs before the limit strength condition is reached, a somewhat lower stick force at limit strength may be acceptable. The acceptability of a stick force of less than 50 pounds at the limit strength condition will depend upon the intensity of the buffet, the adequacy of the warning margin (i.e., the load factor increment between the heavy buffet and the limit strength condition), and the stick force characteristics. In determining the limit strength condition for each critical component, the contribution of buffet loads to the overall maneuvering loads should be taken into account.

(B) This minimum stick force applies in the enroute configuration with the airplane trimmed for straight flight, at all speeds above the minimum speed at which the limit strength condition can be achieved without stalling. No minimum stick force is specified for other configurations, but the requirements of § 25.143(f) are applicable in these conditions.

(iii) Stick Force Characteristics.

(A) At all points within the buffet onset boundary determined in accordance with § 25.25 1 (e), but not including speeds above V_{FC}/M_{FC}, the stick force should increase progressively with increasing load factor. Any reduction in stick force gradient with change of load factor should not be so large or abrupt as to impair significantly the ability of the pilot to maintain control over the load factor and pitch attitude of the airplane.

(B) Beyond the buffet onset boundary, hazardous stick force characteristics should not be encountered within the permitted maneuvering envelope as limited by paragraph 20e(2)(iii)(C). It should be possible, by use of the primary longitudinal control alone, to rapidly pitch the airplane nose down so as to regain the initial trimmed conditions. The stick force characteristics demonstrated should comply with the following:

(1) For normal acceleration increments of up to 0.3g beyond buffet onset, where these can be achieved, local reversal of the stick force gradient may be acceptable, provided that any tendency to pitch up is mild and easily controllable.

(2) For normal acceleration increments of more than 0.3g beyond buffet onset, where these can be achieved, more marked reversals of the stick force gradient may be acceptable. It should be possible to contain any pitch-up tendency of the airplane within the allowable maneuvering limits, without applying push forces to the control column and without making a large and rapid forward movement of the control column.

(C) In flight tests to satisfy paragraphs 20f(2)(iii)(A) and (B), the load factor should be increased until either:

(1) The level of buffet becomes sufficient to provide a strong and effective deterrent to any further increase of the load factor; or

(2) Further increase of the load factor requires a stick force in excess of 150 pounds (or in excess of 100 pounds when beyond the buffet onset boundary) or is impossible because of the limitations of the control system; or

(3) The positive limit maneuvering load factor established in compliance with § 25.337(b) is achieved.

(iv) Negative Load Factors. It is not intended that a detailed flight test assessment of the maneuvering characteristics under negative load factors should necessarily be made throughout the specified range of conditions. An assessment of the characteristics in the normal flight envelope involving normal accelerations from 1g to zero g will normally be sufficient. Stick forces should also be assessed during other required flight testing involving negative load factors. Where these assessments reveal stick force gradients that are unusually low, or that are subject to significant variation, a more detailed assessment, in the most critical of the specified conditions, will be required. This may be based on calculations, provided they are supported by adequate flight test or wind tunnel data.

21. LONGITUDINAL CONTROL - § 25.145.

a. Explanation.

(1) Section 25.145(a) requires that there be adequate longitudinal control to promptly pitch the airplane nose down from at, or near the stall to return to the original trim speed. The intent is to insure sufficient pitch control if inadvertently slowed to the point of stall. Though § 25.145(a)(4) requires testing at power settings between idle and maximum continuous, it is not intended that airplanes should be taken to the point of stall with high power settings; this situation is addressed by basing the minimum test speed on stall warning plus a pilot recognition time, as described in paragraph 21(b)(1)(ii).

* (2) Section 25.145(b) requires changes to be made in flap position, power, and speed without undue effort when retrimming is impractical. The purpose is to ensure that any of these changes are possible assuming that the pilot finds it necessary to devote at least one hand to the initiation of the desired operation without being overpowered by the primary airplane controls. The objective is to show that an excessive change in trim does not result from the application or removal of power or the extension or retraction of wing flaps. The presence of gated positions on the flap control does not affect the requirement to demonstrate full flap extensions and retractions without changing the trim control. Compliance with § 25.145(b) also requires that the relation of control force to speed be such that reasonable changes in speed may be made without encountering very high control forces.

(3) Section 25.145(c) contains requirements associated primarily with attempting a go-around maneuver from the landing configuration. Retraction of the high-lift devices from the landing configuration should not result in a loss of altitude if the power or thrust controls are moved to the go-around setting at the same time that flap/slat retraction is begun. The design features involved with this requirement are the rate of flap/slat retraction, the presence of any flap gates, and the go-around power or thrust setting. The go-around power or thrust setting should be the same as is used to comply with the approach and landing climb performance requirements of §§ 25.121(d) and 25.119, and the controllability requirements of §§ 25.145(b)(3), 25.145(b)(4), 25.145(b)(5), 25.149(f), and 25.149(g). The controllability requirements may limit the go-around power or thrust setting. *

* (4) Section 25.145(d) provides requirements for demonstrating compliance with § 25.145(c) when gates are installed on the flap selector. Section 25.145(d) also specifies gate design requirements. Flap gates, which prevent the pilot from moving the flap selector through the gated position without a separate and distinct movement of the selector, allow compliance with these requirements to be demonstrated in segments. High lift device retraction must be demonstrated beginning from the maximum landing position to the first gated position, between gated positions, and from the last gated position to the fully retracted position.

(i) If gates are provided, § 25.145(d) requires the first gate from the maximum landing position to be to be located at a position corresponding to a go-around configuration. If there are multiple go-around configurations, the following criteria should be considered when selecting the location of the gate:

(A) The expected relative frequency of use of the available go-around configurations.

(B) The effects of selecting the incorrect high-lift device control position.

(C) The potential for the pilot to select the incorrect control position, considering the likely situations for use of the different go-around positions.

(D) The extent to which the gate(s) aid the pilot in quickly and accurately selecting the correct position of the high-lift devices.

(ii) Regardless of the location of any gates, initiating a go-around from any of the approved landing positions should not result in a loss of altitude. Therefore, § 25.145(d) requires that compliance with § 25.145(c) be demonstrated for retraction of the high-lift devices from each approved landing position to the control position(s) associated with the high-lift device configuration(s) used to establish the go-around procedure(s) from that landing position. A separate demonstration of compliance with this requirement should only be necessary if there is a gate between an approved landing position and its associated go-around position(s). If there is more than one associated go-around position, conducting this test using the go-around configuration with the most retracted high-lift device position should suffice, unless there is a more critical case. If there are no gates between any of the landing flap positions and their associated go-around positions, the demonstrations discussed in paragraph 2 1 a(4) above should be sufficient to show compliance with this provision of § 25.145(d). *

b. Procedures. The following test procedures outline an acceptable means for demonstrating compliance with § 25.145. These tests may be conducted at an optional altitude in accordance with § 25.2 1 (c). Where applicable, the conditions should be maintained on the engines throughout the maneuver.

(1) Longitudinal control recovery, § 25.145(a):

(i) Configuration:

(A) Maximum weight or a lighter weight if considered more critical.

(B) Aft c.g. position.

(C) Landing gear extended.

(D) Wing flaps retracted and extended to the maximum landing position.

(E) Engine power at idle and maximum continuous.

(ii) Test procedure: The airplane should be trimmed at the speed for each configuration as prescribed in § 25.103(b)(1). The airplane should then be decelerated at 1 knot per second with wings level. For tests at idle power, it should be demonstrated that the nose can be pitched down from any speed between the trim speed and the stall. Typically, the most critical point is at the stall when in stall buffet. The rate of speed increase during the recovery should be adequate to promptly return to the trim point. Data from the stall characteristics testing can be used to evaluate this capability at the stall. For tests at maximum continuous power, the maneuver need not be continued for more than one second beyond the onset of stall warning. However, the static longitudinal stability characteristics during the maneuver, and the nose down control power remaining at the end of the maneuver, must be sufficient to assure that a prompt recovery to the trim speed could be attained if the airplane is slowed to the point of stall.

(2) Longitudinal control, flap extension, § 25.145(b)(1).

(i) Configuration:

(A) Maximum landing weight or a lighter weight if considered more critical.

(B) Critical c.g. position.

(C) Wing flaps retracted.

(D) Landing gear extended.

(E) Engine power at flight idle.

(ii) Test procedure: The airplane should be trimmed at a speed of $1.4V_S$. The flaps should be extended to the maximum landing position as rapidly as possible while maintaining approximately $1.4V_S$ for the flap position existing at each instant throughout the maneuver. The control forces should not exceed 50 lbs. (the maximum force for short term application that can be applied readily by one hand) throughout the maneuver without changing the trim control.

(3) Longitudinal control, flap retraction, §§ 25.145(b)(2) & (3).

(i) Configuration:

(A) Maximum landing weight or a lighter weight if considered more critical.

(B) Critical c.g. position.

(C) Wing flaps extended to maximum landing position.

(D) Landing gear extended.

(E) Engine power at flight idle and the go-around power or thrust setting.

(ii) Test procedure: With the airplane trimmed at $1.4V_S$, the flaps should be retracted to the full up position while maintaining approximately $1.4V_S$ for the flap position existing at each instant throughout the maneuver. The longitudinal control force should not exceed 50 lbs. throughout the maneuver without changing the trim control.

(4) Longitudinal control, power application, §§ 25.145(b)(4) & (5)

(i) Configuration:

(A) Maximum landing weight or a lighter weight if considered more critical.

(B) Critical c.g. position.

(C) Wing flaps retracted and extended to the maximum landing position.

(D) Landing gear extended.

(E) Engine power at flight idle.

(ii) Test procedure: The airplane should be trimmed at a speed of $1.4V_S$. Quickly set go-around power or thrust while maintaining the speed of $1.4V_S$. The longitudinal control force should not exceed 50 pounds throughout the maneuver without changing the trim control.

(5) Longitudinal control, airspeed variation, § 25.145(b)(6).

(i) Configuration:

(A) Maximum landing weight or a lighter weight if considered more critical.

(B) Most forward c.g. position.

(C) Wing flaps extended to the maximum landing position.

(D) Landing gear extended.

(E) Engine power at flight idle.

(ii) Test Procedure: The airplane should be trimmed at a speed of $1.4V_S$. The speed should then be reduced to $1.1\ V_S$ and then increased to $1.7V_S$, or the flap placard speed, V_{FE}, whichever is lower. The longitudinal control force should not be greater than 50 lbs. Data from the static longitudinal stability tests in the landing configuration at forward c.g., § 25.175(d), may be used to show compliance with this requirement.

(6) Longitudinal control, flap retraction and power application, § 25.145(c).

(i) Configuration:

(A) Critical combinations of maximum landing weights and altitudes.

(B) Critical c.g. position.

(C) Wing flaps extended to the maximum landing position and gated position, if applicable.

(D) Landing gear extended.

(E) Engine power for level flight at a speed of $1.1\ V_S$ for propeller driven airplanes, or $1.2V_S$ for turbojet powered airplanes.

* (ii) Test procedure. With the airplane stable in level flight at a speed of $1.1\ V_S$ for propeller driven airplanes, or $1.2V_S$ for turbojet powered airplanes, retract the flaps to the full up position, or the next gated position, while simultaneously setting go-around power or thrust. Use the same power or thrust as is used to comply with the performance requirement of § 25.12 1 (d), as limited by the applicable controllability requirements. It must be possible, without requiring exceptional piloting skill, to prevent losing altitude during the maneuver. Trimming is permissible at any time during the maneuver. If gates are provided, conduct this test beginning from the maximum landing flap position to the first gate, from gate to gate, and from the last gate to the fully retracted position. If there is a gate between any landing position and its associated go-around position(s), this test should also be conducted from that landing position through the gate to the associated go-around position. If there is more than one associated go-around position, this additional test should be conducted using the go-around position corresponding to the most retracted flap position, unless another position is more critical. Keep the landing gear extended throughout the test. *

(7) Longitudinal control, extreme out-of-trim takeoff conditions, §§ 25.107(e)(4) and 25.143(a)(1).

(i) Configuration:

(A) Critical combinations of takeoff weight and forward and aft c.g. limits.

(B) Wing flaps in all takeoff positions.

(C) All engines operating at maximum takeoff power or thrust.

(ii) The airplane should be loaded to weight and c.g. combinations representing critical comers of the takeoff envelope for both forward and aft c.g. limits. The longitudinal trim should be set for the extreme opposite c.g. (e.g., load to forward c.g. limit at a given weight and set the longitudinal trim for the aft c.g. limit at that weight) as presented in the takeoff trim "green-band" including the takeoff warning system rigging tolerance. Accomplish a takeoff at normal operating speeds and evaluate the control forces and airplane responses to control inputs. In accordance with § 25.107(e)(4), this out-of-trim takeoff configuration must not result in any unsafe flight characteristics.

22. DIRECTIONAL AND LATERAL CONTROL - § 25.147.

a. Explanation.

(1) Sections 25.147(a) and (b) provide criteria for investigation of the airplane to determine if it may have dangerous characteristics such as rudder lock or loss of directional control if it is maneuvered with the rudder only, maintaining wings level, when one or two critical engines are inoperative. Some yaw should be possible into the operating engine(s). It should also be possible to make reasonably sudden heading changes of up to 15 degrees, as limited by rudder force or deflection, toward the inoperative engine(s). The intention of the requirement is that the airplane can be yawed as prescribed without the need for application of bank angle. Small variations of bank angle that are inevitable in a realistic flight test demonstration are acceptable.

(2) Sections 25.147(c) and (d) require an airplane to be easily controllable with the critical engine(s) inoperative. Roll response, § 25.147(e), should be satisfactory for takeoff, approach, landing, and high speed configurations. Any permissible configuration that could affect roll response should be evaluated.

b. Procedures.

(1) Directional Control - General, § 25.147(a).

(i) Configuration:

(A) Maximum landing weight.

(B) Most aft c.g. position.

(C) Wing flaps extended to the approach position.

(D) Landing gear retracted.

(E) Yaw SAS on, and off if applicable.

(F) Operating engine(s) at the power for level flight at $1.4V_S$, but not more than maximum continuous power.

(G) Inoperative engine that would be most critical for controllability, with propeller feathered, if applicable.

(ii) Test Procedure. The airplane should be trimmed in level flight at the most critical altitude in accordance with § 25.21(c). Reasonably sudden changes in heading to the left and right, using ailerons to maintain approximately wings level flight, should be made demonstrating a change of up to 15 degrees or that at which 150 lbs. rudder force is required. The airplane should be controllable and free from any hazardous characteristics during this maneuver. For the airplane equipped with a rudder boost system, the evaluation should be done without rudder boost if the boost system can be inoperative.

(2) Directional Control - Four or More Engines, § 25.147(b).

(i) Configuration:

(A) Maximum landing weight.

(B) Most forward c.g. position.

(C) Wing flaps in the most favorable climb position (normally retracted).

(D) Landing gear retracted.

(E) Yaw SAS on, and off if applicable.

(F) Operating engines at the power required for level flight at $1.4V_{S1}$, but not more than maximum continuous power.

(G) Two inoperative engines that would be most critical for controllability with (if applicable) propellers feathered.

(ii) Test Procedure. The procedure outlined in subparagraph 22b(1)(ii), above, is applicable to this test.

(3) Lateral Control - General, § 25.147(c).

(i) Configuration:

(A) Maximum takeoff weight.

(B) Most aft c.g. position.

(C) Wing flaps in the most favorable climb position,

(D) Landing gear retracted and extended.

(E) Yaw SAS on, and off if applicable.

(F) Operating engine(s) at maximum continuous power.

(G) The inoperative engine that would be most critical for controllability, with the propeller feathered, if applicable.

(ii) Test Procedure. With the airplane trimmed at $1.4V_S$, turns with a bank angle of 20 degrees should be demonstrated with and against the inoperative engine from a steady climb at $1.4V_{S1}$. It should not take exceptional piloting skill to make smooth, predictable turns.

(4) <u>Lateral Control - Four or More Engines, § 25.147(d)</u>.

(i) Configuration:

(A) Maximum takeoff weight.

(B) Most aft c.g. position.

(C) Wing flaps in the most favorable climb position.

(D) Landing gear retracted and extended.

(E) Yaw SAS on, and off if applicable.

(F) Operating engines at maximum continuous power.

(G) Two inoperative engines most critical for controllability, with propellers feathered, if applicable.

(ii) Test Procedure: The procedure outlined in paragraph 22b(3)(ii) is applicable to this test.

(5) <u>Lateral Control - All Engines Operating, § 25.147(e)</u>.

(i) Configuration: All configurations within the flight envelope for normal operation.

(ii) Test Procedure: This is primarily a qualitative evaluation that should be conducted throughout the test program. Roll performance should be investigated throughout the flight envelope, including speeds to V_{FC}/M_{FC}, to ensure adequate peak roll rates for safety, considering the flight condition, without excessive control force or travel. Roll response during sideslips expected in service should provide maneuvering capabilities adequate to recover from such conditions. Approach and landing configurations should be carefully evaluated to ensure adequate control to compensate for gusts and wake turbulence while in close proximity to the ground.

23. MINIMUM CONTROL SPEED - § 25.149.

a. Explanation. Section 25.149 defines requirements for minimum control speeds during takeoff climb (V_{MC}), during takeoff ground roll (V_{MCG}), and during approach and landing (V_{MCL} and V_{MCL-2}). The V_{MC} (commonly referred to as V_{MCA}) requirements are specified in §§ 25.149(a), (b), (c) and (d); the V_{MCG} requirements are described in § 25.149(e); and the V_{MCL} and V_{MCL-2} requirements are covered in §§ 25.149(f), (g) and (h). Section 25.149(a) states that "...the method used to simulate critical engine failure must represent the most critical mode of powerplant failure with respect to controllability expected in service." That is, the thrust loss from the inoperative engine must be at the rate that would occur if an engine suddenly became inoperative in service. Prior to Amendment 25-42 to § 25.149, the regulation required that rudder control forces must not exceed 180 lbs. With the adoption of Amendment 25-42, rudder control forces became limited to 150 lbs. The relationships between V_{EF}, V_1, and V_{MCG} are discussed in paragraph 10, Takeoff and Takeoff Speeds, and paragraph 11, Accelerate-Stop Distance.

b. Procedures.

(1) General.

(i) Prior to beginning the minimum control speed tests, an evaluation should be conducted to determine which engine's failure will result in the largest asymmetric yawing moment (i.e., the "critical" engine). This is typically done by setting one outboard engine to maximum thrust, setting the corresponding opposite engine at idle, and decelerating with wings level until full rudder is required. By alternating power on/power off from left to right, the critical engine can be defined as the idle engine that requires the highest minimum speed to maintain a constant heading with full rudder deflection.

(ii) For propeller-driven airplanes, V_{MCA}, V_{MCG}, and V_{MCL} (and V_{MCL-2}, as applicable) should be determined by rendering the critical engine(s) inoperative and allowing the propeller to attain the position it automatically assumes. However, for some engine/propeller installations, a more critical drag condition could be produced as the result of a failure mode that results in a partial power condition that does not actuate the automatic propeller drag reduction system (e.g., autofeather system). One example is a turbopropeller installation that can have a fuel control failure, which causes the engine to go to flight idle, resulting in a higher asymmetric yawing moment than would result from an inoperative engine. In such cases, the minimum control speed tests must be conducted using the most critical failure mode. For propeller-driven airplanes where V_{MCA} is based on operation of a propeller drag reduction system, V_{MCA} should also be defined with the critical engine at idle to address the training situation where engine failure is simulated by retarding the critical engine to idle. If V_{MCA} at idle is more than one knot greater than for the engine failure with an operating drag reduction system, the idle engine V_{MCA} should be included in the Normal Procedures section of the Airplane Flight Manual (AFM) as advisory information to maintain the level of safety in the aforementioned training situation.

(iii) Airplane Flight Manual values of V_{MCA}, V_{MCG}, and V_{MCL} (and V_{MCL-2}, as applicable) should be based on the maximum net thrust reasonably expected for a production engine. These speeds should not be based on specification thrust, since this value represents the minimum thrust guaranteed by the engine manufacturer, and the resulting minimum control speeds will not be representative of what could be achieved in operation. The maximum thrust used for scheduled AFM minimum control speeds should represent the high side of the tolerance band, but may be determined by analysis instead of tests.

(iv) When determining V_{MCA}, V_{MCL}, and V_{MCL-2}, consideration should be given to the adverse effect of maximum approved lateral fuel imbalance on lateral control avaiiability. This is especially of concern if tests or analysis show that the lateral control available is the determining factor of a particular V_{MC}.

(2) <u>Minimum Control Speeds - Air</u> (V_{MCA}).

(i) To comply with the V_{MCA} requirements, the following two conditions must be satisfied: (Separate tests are usually conducted to show compliance with these two requirements.)

(A) The stabilized (static) condition where constant heading is maintained without exceeding a 5-degree bank angle, and

(B) The dynamic condition in which control is maintained without exceeding a heading change of 20 degrees.

(ii) Static Test Procedure and Required Data.

(A) To determine V_{MCA}, use the configuration specified in § 25.149, except that V_{MCA} is normally determined at minimum weight in order to minimize the stall speed and because static V_{MCA} decreases with increased weight if a 5-degree bank angle is used. The requirement of § 25.149(c) that V_{MCA} not exceed $1.2V_S$ is based on V_S at maximum sea level takeoff weight. With the critical engine inoperative, the corresponding opposite engine should be adjusted to maximum takeoff power/thrust, and the airspeed decreased until heading can just be maintained with full rudder and no more than a 5degree bank into the operating engine. For airplanes with more than two engines, the inboard engine(s) may be set to any thrust necessary to assist in developing the desired level of asymmetric thrust, or to achieve the desired flightpath angle (normally level flight).

(B) If the maximum asymmetric thrust that is permitted by the AFM operating limitations was maintained at the test day V_{MCA}, and the rudder pedal force did not exceed the limit specified in § 25149(d), the resulting speed may be used as the single value of V_{MCA} for the airplane. If, at the option of the applicant, the AFM value of V_{MCA} is to vary with pressure altitude and temperature, the test day minimum control speed and the corresponding thrust should be used to calculate an equivalent yawing moment coefficient (C,). This C_N value may then be used to calculate V_{MCA} as a function of takeoff thrust, thus permitting V_{MCA} to be scheduled as a function of pressure altitude and temperature for takeoff data expansion and presentation in the AFM (See Appendix 3 for further discussion of V_{MCA} correction).

(C) If maximum allowable takeoff thrust could not be developed at the flight test conditions, but maximum rudder deflection was achieved, then the V_{MCA} value corresponding to sea level standard day maximum asymmetric thrust may be calculated from the C_N attained at the test value of V_{MCA}. Extrapolation using this constant C_N method is limited to 5 percent of the test day asymmetric thrust, and is only permitted if the rudder pedal force at the test day V_{MCA} was not more than 95 percent of the limit value specified in § 25.149(d). For extrapolation beyond 5 percent thrust, a more rigorous analysis is required, which includes all the applicable stability and control terms (See Appendix 3 for further discussion of V_{MCA} correction).

(D) If V_{MCA} could not be achieved due to stall buffet, or excessive rudder pedal force, a parametric investigation should be undertaken to determine whether V_{MCA} is limited by stall speed, maximum rudder deflection, or maximum allowable rudder pedal force (See Appendix 4).

(iii) Dynamic Test Procedures and Required Data.

(A) After the static V_{MCA} tests have been completed, dynamic engine cuts should be evaluated at a series of decreasing airspeeds to show that sudden engine failure at any speed down to the static V_{MCA} value meets the requirements of § 25.149. The dynamic V_{MCA} test is conducted by applying the maximum approved power/thrust to all outboard engines, stabilizing at the test airspeed, and then cutting fuel to the critical engine. It must be possible to recover to a constant heading, without deviating more than 20 degrees from the original heading, while maintaining the test airspeed, without reducing power/thrust on the operating engine(s), and without exceeding the rudder pedal force limit of § 25.149(d). If the dynamic tests result in a V_{MCA} greater than the static value, the increment between the static and dynamic V_{MCA} at the same altitude should be added to the sea level extrapolated value. If the dynamic value is less than the static value, the static V_{MCA} must be used for the AFM data expansion.

(B) If static V_{MCA} is near stall speed at the minimum practicable test weight, or if the thrust-to-weight ratio (T/W) results in a trimmed pitch attitude of more than 20 degrees, it is not feasible to attempt to accurately define a quantitative value of V_{MCA} using a sudden engine cut because of the dynamics of the rapid pitchdown maneuver required, and the hazard associated with a potential spin entry. Additionally, an extreme nose up attitude followed by an engine cut is not representative of an operational takeoff engine failure. Since § 25.107(e)(l)(ii) requires V_R to be not less than $1.05V_{MCA}$, and there is some additional speed increase prior to lift off, a transport airplane is typically never airborne below approximately $1.08V_{MCA}$. Therefore, instead of using the dynamic method to define V_{MCA} for these aircraft with high T/W or stall speed coincident with V_{MCA}, it is more appropriate for a dynamic engine cut to be evaluated only for acceptable controllability, and at a more representative speed. For these airplanes, a dynamic engine cut should be evaluated at an airspeed of either $1.1V_S$ or 1.1 V_{MCA} (static), whichever is greater. During the entry to, and recovery from this maneuver, all the requirements of § 25.149(d) must be met.

(C) For airplanes with rudder travel-limited V_{MCA}'s that have increased thrust engines installed, with no changes to the airframe's geometric layout or dimensions, it may not be necessary to conduct dynamic V_{MCA} flight testing if the thrust has not increased more than 10 percent above the level at which dynamic V_{MCA} had previously been demonstrated (see Appendix 3 of this AC).

(3) Minimum Control Speed - Ground (V_{MCG}) - § 25.149(e).

(i) It must be demonstrated that, when the critical engine is suddenly made inoperative at V_{MCG} during the takeoff ground roll, the airplane is safely controllable if the takeoff is continued. During the demonstration, the airplane must not deviate more than 30 ft. (25 ft. prior to Amendment 25-42) from the pre-engine-cut projected ground track. The critical engine)for ground minimum control speed testing should be determined during the takeoff ground run using techniques similar to these described in paragraph 23b(1). If there is a significant difference in left and right rudder deflection, the loss of asymmetric propeller disc loading, due to near zero angle of attack during the takeoff roll, could result in the critical engine being on the opposite side of the airplane relative to the airborne minimum control speed tests.

(ii) Tests may be conducted by abruptly retarding the critical engine to idle to establish the minimum value of V_{MCG}. At least one fuel cut should be made at each maximum asymmetric thrust level desired to be certificated to investigate the more rapid thrust decay associated with this type of engine failure. At the applicant's option, to account for crosswind test conditions, the runs may be made on reciprocal headings, or an analytical correction may be applied to determine the zero crosswind value of V_{MCG}.

(iii) During determination of V_{MCG}, engine failure recognition should be provided by:

(A) The pilot feeling a distinct change in the directional tracking characteristics of the airplane; or

(B) The pilot seeing a directional divergence of the airplane with respect to the view outside the airplane.

(iv) Control of the airplane should be accomplished by use of the rudder only. All other controls, such as ailerons and spoilers, should only be used to correct any alterations in the airplane attitude and to maintain a wings level condition. Use of those controls to supplement the rudder effectiveness should not be allowed. Care should also be taken not to inadvertently apply brake pressure during large rudder deflections, as this will invalidate the test data.

(v) V_{MCG} testing should be conducted at the heaviest weight where V_{MCG} may impact the AFM V, schedule.

(vi) V_{MCG} testing should be conducted at aft c.g. and with the nose wheel free to caster, to minimize the stabilizing effect of the nose gear. If the nose wheel does not caster freely, the test may be conducted with enough nose up elevator applied to lift the nose wheel off the runway.

(vii) For airplanes with certification bases prior to Amendment 25-42, V_{MCG} values may be demonstrated with nose wheel rudder pedal steering operative for dispatch on wet runways. The test should be conducted on an actual wet runway. The test(s) should include engine failure at or near a minimum V_{EF} associated with minimum V_R to demonstrate adequate controllability during rotation, liftoff, and the initial climbout. The V_{MCG} values obtained by this method are applicable for wet or dry runways only, not for icy runways.

(4) Minimum Control Speed During Approach and Landing V_{MCL} - § 25.149(f).

(i) This section is intended to ensure that the airplane is safely controllable following an engine failure during an all-engines-operating approach and landing. From a controllability standpoint, the most critical case consists of an engine failing after the power or thrust has been increased to perform a go-around from an all-engines-operating approach. Section 25.149(f) requires the minimum control speed to be determined that allows a pilot of average skill and strength to retain control of the airplane after the engine becomes inoperative and to maintain straight flight with less than 5 degrees of bank angle. Section 25.149(h) requires that sufficient lateral control be available at V_{MCL} to roll the airplane through an angle of 20 degrees, in the direction necessary to initiate a turn away from the inoperative engine, in not more than five seconds when starting from a steady straight flight condition.

(ii) Conduct this test using the most critical of the all-engines-operating approach and landing configurations or, at the option of the applicant, each of the all-engines-operating approach and landing configurations. The procedures given in paragraphs 23b(2)(ii) and (iii) for V_{MCA} may be used to determine V_{MCL}, except that flap and trim settings should be appropriate to the approach and landing configurations, the power or thrust on the operating engine(s) should be set to the go-around power or thrust setting, and compliance with all V_{MCL} requirements of §§ 25.149(f) and (h) must be demonstrated.

(iii) For propeller driven airplanes, the propeller must be in the position it achieves without pilot action following engine failure, assuming the engine fails while at the power or thrust necessary to maintain a three degree approach path angle.

(iv) At the option of the applicant, a one-engine-inoperative landing minimum control speed, $V_{MCL(1\ out)}$, may be determined in the conditions appropriate to an approach and landing with one engine having failed before the start of the approach. In this case, only those configurations recommended for use during an approach and landing with one engine inoperative need be considered. The propeller of the inoperative engine, if applicable, may be feathered throughout. The resulting value of $V_{MCL(1\ out)}$ may be used in determining the recommended procedures and speeds for a one-engine-inoperative approach and landing.

(5) Minimum Control Speed with Two Inoperative Engines During Approach and Landing (V_{MCL-2}) - § 25.149(g).

(i) For airplanes with three or more engines, V_{MCL-2} is the minimum speed for maintaining safe control during the power or thrust changes that are likely to be made following the failure of a second critical engine during an approach initiated with one engine inoperative.

(ii) For propeller driven airplanes, the propeller of the engine that is inoperative at the beginning of the approach may be in the feathered position. The propeller of the more critical engine must be in the position it automatically assumes following engine failure.

(iii) Conduct this test using the most critical approved one-engine-inoperative approach or landing configuration (usually the minimum flap deflection), or at the option of the applicant, each of the approved one-engine-inoperative approach and landing configurations. The following demonstrations are required to determine V_{MCL-2}:

(A) With the power or thrust on the operating engines set to maintain a minus 3 degree glideslope with one critical engine inoperative, the second critical engine is made inoperative and the remaining operating engine(s) are advanced to the go-around power or thrust setting. The V_{MCL-2} speed is established by the procedures presented in paragraphs 23b(2)(ii) and (iii) for VMCA, except that flap and trim settings should be appropriate to the approach and landing configurations, the power or thrust on the operating engine(s) should be set to the go-around power or thrust setting, and compliance with all V_{MCL-2} requirements of §§ 25.149(g) and (h) must be demonstrated.

(B) With power on the operating engines set to maintain a minus 3 degree glideslope, with one critical engine inoperative:

(1) Set the airspeed at the value determined above in step (A) and, with zero bank angle, maintain a constant heading using trim to reduce the control force to zero. If full trim is insufficient to reduce the control force to zero, full trim should be used plus control deflection as required; and

(2) Make the second critical engine inoperative and retard the remaining operating engine(s) to minimum available power without changing the directional trim. The V_{MCL-2} determined in paragraph (A) is acceptable if constant heading can be maintained without exceeding a 5 degree bank angle and the limiting conditions of § 25.149(h).

(C) Starting from a steady straight flight condition, demonstrate that sufficient lateral control is available at V_{MCL-2} to roll the airplane through an angle of 20 degrees in the direction necessary to initiate a turn away from the inoperative engines in not more than five seconds. This maneuver may be flown in a bank-to-bank roll through a wings level attitude.

(iv) At the option of the applicant, a two-engines-inoperative landing minimum control speed, $V_{MCL-2(2\ out)}$, may be determined in the conditions appropriate to an approach and landing with two engines having failed before the start of the approach. In this case, only those configurations recommended for use during an approach and landing with two engines inoperative need be considered. The propellers of the inoperative engines, if applicable, may be feathered throughout. The values of V_{MCL-2} or $V_{MCL-2(2\ out)}$ should be used as guidance in determining the recommended procedures and speeds for a two-engines-inoperative approach and landing.

(6) Autofeather Effects. Where an autofeather or other drag limiting system is installed, and will be operative at approach power settings, its operation may be assumed in determining the propeller position achieved when the engine fails. Where automatic feathering is not available, the effects of subsequent movements of the engine and propeller controls should be considered, including fully closing the power lever of the failed engine in conjunction with maintaining the go-around power setting on the operating engines.

Section 4. LANDING GEAR

48. - 5 1. [RESERVED]

52. RETRACTING MECHANISM - § 25.729.

a. Explanation. None.

b. Procedures.

(1) In accordance with the provisions of § 25.729, flight tests should be conducted to demonstrate the ability of the landing gear and associated components, in their heaviest configuration, to properly extend and retract at:

(i) V_{LO} (the placard airspeed) in the cruise configuration at near lg flight and normal yaw angles; and

(ii) airspeeds and flap settings corresponding to typical landings. The landing gear operating placard airspeed, V_{LO}, established in accordance with $25.15 15(a), should not exceed the 1.6 V_{S1} design value of § 25.729(a)(1)(ii).

NOTE: "Normal" yaw angles are those associated with engine-out flight and counteracting crosswinds of up to 20 knots.

(2) The alternate extend system should be demonstrated at airspeeds up to V_{LO} at near 1 g flight and normal yaw angles. An envelope of emergency extension capability should be established and presented in the emergency operating procedures section of the AFM. (Refer to NOTE paragraph above.)

(3) Operation test.- § 25.729(d).

(i) The engine-out gear retraction time should be determined from flight tests with one engine at idle power and the operating engine(s) adjusted to provide the lowest thrust-to-weight ratio to be certificated. The hydraulic system should be in the critical configuration corresponding to an actual engine failure condition. The airplane should be stabilized on a steady heading before gear retraction is initiated. The resulting gear retraction time will be used in developing AFM takeoff flight path performance information in accordance with § 25.111.

(ii) Gear retraction time is the time from landing gear lever movement to the **"UP"** position until the last landing gear, including doors, is in the retracted configuration. Allowance should be made for any delays associated with the landing gear indication system.

(4) Position indication and aural warning, § 25.729(e): It should be confirmed that the actual landing gear position agrees with the position indicated on the landing gear indicator.

Landing gear **aural** warning should meet the intent of §§ 25.729(e)(2) through (e)(4). A combination of flight tests, ground tests, and analysis may be used to show compliance with these requirements.

53. WHEELS - § 25.731.

a. References.

(1) Technical Standard Order (TSO) C26c, "Aircraft Wheels and Wheel-Brake Assemblies, with Addendum I," dated May 18,1984, for additional guidance.

(2) Paragraph 55b(4)vi of this AC, Wheel Fuse Plugs.

(3) Paragraph 55c(7) of this AC, Wheel Fuse Plug Design.

(4) Advisory Circular 2 1-29A, " Detecting and Reporting Suspected Unapproved Parts," dated July 16, 1992.

b. Explanation.

(1) Background.

(i) Original guidelines for wheels in § 4b.335 of the Civil Air Regulations (CAR) were superseded by TSO-C26 and subsequent revisions. Early versions of TSO-C26 referred to minimum standard requirements in versions of Society of Automotive Engineers (SAE) Aeronautical Standard (AS) 227. Minimum standards were subsequently specified in TSO-C26b and later revisions. For braked wheels, wheels and brakes must be approved as an assembly in recognition of design and safety interdependencies associated with thermal control, vibration control, structural stresses, etc. References (2) and 3) of paragraph a, above, provide insight into the criticality of proper fuse function to support airworthiness. As demands increased for longer life wheels and more robust designs, changes were introduced such as the addition of combined vertical and side loads for a portion of roll testing; an increase in roll miles at maximum static load from 1,000 to 2,000 miles; and addition of a roll-on-rim requirement to increase robustness in wheel flange areas.

(ii) In most cases, wheels are usually removed from service based upon condition. Typically, inspection frequency will increase as life on a particular wheel is accumulated in accordance with the wheel and brake suppliers Component Maintenance Manual (CMM). If wheel failures occur on the airplane, they typically occur when the airplane is on the ground with wheel and tire assembly loaded.

(iii) The trend in certain airplane manufacturer specifications is to place additional longevity and safety focused test requirements on wheel and brake suppliers. Added requirements, such as fail safe design verification(s), testing to failure of uncorroded and corroded wheels, and mandated use of overpressurization protection devices (in addition to fuses) have been incorporated. With the introduction of longer life tires, the demands on wheels and components, such as wheel bearings, have further intensified as landings between inspections at tire overhauls have increased. In addition, airplane manufacturers should be involved in wheel design, test, and manufacturer approvals to ensure that airplane specific needs have been addressed. For example, at least one airplane manufacturer specifies a missing wheel tie bolt requirement so that Minimum Equipment List (MEL) dispatch relief can be provided for a limited number of cycles. As a second example, individual airplane manufacturers may specify intensified wheel load and/or test requirements to account for various tire failure modes on multi-wheeled landing gear truck and other airplane landing gear configurations. Therefore, continued airworthiness of a particular wheel/tire or wheel/brake/tire assembly is usually demonstrated by compliance with airplane manufacturer requirements and not TSO minimum standards.

(iv) Separate wheel applicable TSO and (if applicable) airplane manufacturer tests arc performed with radial and bias tires due to different tire-to-wheel interface loading and resultant wheel stress pattern and deflection/clearance differences. For braked wheels, separate wheel and brake assembly tests are performed with radial and bias tires due to differences in tire energy absorption that may be encountered. Some significant differences in wheel life have been reported by one wheel and brake supplier in one case using bias tires from different tire manufacturers. Typically, however, wheel/tire, or wheel/brake/tire assembly tests using different manufacturer bias tires have not been shown to be ncccssary.

(v) Wheel bearings in transport category airplane wheels should bc qualified as part of the wheel assembly. Industry experience indicates that qualification of a specific manufacturer's bearing(s) in a given wheel assembly is required to assure proper performance and airworthiness . Standard part bearing assemblies are not acceptable unless performance can be demonstrated during wheel qualification testing. In response to demands for more robust wheel bearing systems, due in part to longer life tires and increased numbers of landings between wheel and bearing inspections, at least one airplane manufacturer has required qualification testing of each wheel and specific wheel bearing supplier assembly to test requirements exceeding those in TSO-C26c and typical airplane manufacturer specifications. This has required suppliers of larger wheel and brake assemblies to develop special test capabilities for qualification of specific wheel bearing assembly systems (i.e.: bearing manufacturer, grease, seals and other means of grease retention). It has been reported that roller end scoring is the most common mechanism leading to bearing failures on the airplane.

(vi) Improved wheel bearing grease and bearing preload retention means have also been introduced on some recent airplanes to increase wheel bearing longevity in the severe landing gear system environments and account for longer tire lives/ increased intervals between tire changes and inspections. Bearing wheel grease recommendations are usually speci tied in wheel and brake supplier CMMs. Intermixing of bearing cups/rollers/cones from different bearing manufacturers is not recommended on some large transport category airplane wheels due to different roller end scoring resistance capabilities and other often subtle diffcrcnces.

c. Procedures/Method of Compliance. Due to the unique and critical nature of wheel, and wheel and brake designs, and historical airplane and personnel safety problems that have been experienced, compliance should only be approved upon successful completion of applicable TSO and tests any additional airplane manufacturer tests. Guidance should also be solicited from the original wheel and brake supplier(s)/TSO holders on any replacement part(s) to assure that continued airworthiness is not degraded.

54. TIRES - § 25.733 [RESERVED]

55. BRAKES - § 25.735

a. References.

(1) Technical Standard Order (TSO)- C26c, "Aircraft Wheels and Wheel-Brake Assemblies, with Addendum I," dated May 18, 1984.

(2) Advisory Circular 2 1-29A, "Detecting and Reporting Suspected Unapproved Parts," dated July 16, 1992.

b. Explanation.

(1) Background.

* (i) The original objective of § 25.735 (formerly CAR 4b.337) evolved from a study to define a reasonable brake life for operational landings. This element is still retained in the current § 25.735(f), which requires substantiation that the brakes have the ability to absorb the energy resulting from "operational landings at maximum landing weight," and is directly related to the brake energy qualification tests of TSO-C26c. The two methods for compliance, stated in § 25.735(f), are also used in TSO-C26c for the determination of KE_{DL}, the design landing kinetic energy rating for 100 stops at a deceleration rate of not less than 10 ft/sec^2. The initial wear state of the brakes for the testing used to determine KE_{DL} may be selected by the applicant. Any condition representative of service use, including new, and that satisfies TSO-C26c (or acceptable equivalent), may be used. Section 25.735(f) makes reference to "operational landings" and "in the landing configuration," which, in the context of modern transport airplane designs, could encompass a number of trailing edge flap positions and related landing speeds. The landing configuration for showing compliance with § 25.735(f) is left to the option of the applicant, but should be selected on the basis of its being the predominant landing configuration expected in operational service. *

(ii) Over the years, as experience was gained in establishing takeoff and landing field lengths, it became evident that the refused takeoff was critical in determining overall brake capability and could dictate aircraft maximum gross weight for dispatch.

* (iii) Investigation of an RTO overrun accident, in which 80 percent of the brakes on the subject aircraft were at or very near their completely worn state, brought about the need to consider the effect of brake wear state on: 1) energy absorption capability, and 2) stopping capability. As a result, the FAA issued a series of specific airworthiness directives for the *

*existing fleet of transport category airplanes to establish brake wear limits such that the brakes would be capable of absorbing a maximum energy absorption RTO in the fully worn state. The FAA also initiated rulemaking to address energy absorption capability and stopping distance with fully worn brakes for future airplane types. The resulting rule, amendment 25-92, added:

(A) A requirement in § 25.735(h) for the maximum rejected takeoff kinetic energy capacity rating of the aircraft brakes to be determined with the brakes at 100 percent of the allowable wear limit;

(B) A new requirement in § 25.109(i) for the maximum kinetic energy rejected takeoff flight test demonstration to be conducted using brakes that have not more than 10 percent of their allowable wear range remaining; and

(C) A general performance requirement under § 25.101(i) that requires the accelerate-stop and landing distances of §§ 25.109 and 25.125, respectively, to be determined with all wheel brake assemblies at the fully worn limit of their allowable wear range. *

(2) Approval (§ 25.735(a)). In accordance with $21.305, a wheel and brake assembly may be approved under a Technical Standard Order (TSO) issued in accordance with Subpart 0 to 14 CFR part 21; in conjunction with the type certification procedures for the airplane; or in any other manner approved by the Administrator, all of which are normally subject to flight test evaluation. (See TSO-C26c for additional guidance.)

(3) Brake tests (§ 25.735(b)). If the applicant desires to make the maximum possible use of the brakes in establishing the landing distance, and if the contribution of the brakes to the total deceleration is relatively large, the brake system should be designed to permit the application of slightly less than half the braking deceleration developed under the conditions specified in this paragraph. The following dual system is recommended: dual wheel elements (drums or disc units), transmitting elements, power sources, master cylinders, etc., connected to a single pedal on each rudder pedal, such that the failure of any single one of these would leave half the total braking capacity symmetrically disposed about the plane of symmetry of the airplane. With such a system, it should be possible to show compliance with § 25.735(b) by means of calculations based upon the test data necessary to establish the landing distance, plus the brake data calculated by the airplane manufacturer.

(4) If the system is designed so that, under conditions herein specified, appreciably less than half the total braking capacity remains, or if the remaining capacity is asymmetrically disposed, tests should be conducted to determine that half the mean deceleration may, in fact, be developed, and/or that the airplane may be safely controlled directionally while doing so. In order to obtain a minimum landing distance under § 25.125 and at the same time meet the deceleration requirements of § 25.735(b) in the event of failure of the normal brake system, it is common practice to provide an alternate brake system. When hydraulic (or pneumatic) brakes are used in the normal brake system, this alternate means usually consists of a duplicate hydraulic or pneumatic brake system and is commonly referred to as the “emergency brake system.” The following items should be considered in the design of such systems:

(i) Relationship between normal and emergency brake systems. The systems for actuating the normal brake and the emergency brake should be separated so that a failure (i.e., hydraulic leakage of fluid) from one system will not render the other system inoperative. A hydraulic brake assembly may be common to both the normal and emergency brake systems if it is shown that the leakage of hydraulic fluid resulting from failure of the sealing elements in the brake assembly would not reduce the airplane's braking effectiveness below that specified in § 25.735(b).

(ii) Brake controls (§ 25.735(c)). General brake control force and operation should be noted throughout the flight test program to determine that they are satisfactory.

(iii) Brake control valves. In the normal brake systems of all airplanes, the brake valves should be of a type such that the pilots may exercise variable control of the pressure to the brakes. The foregoing provision need not necessarily apply to the emergency brake system, although obviously such a provision would be desirable. Flight tests should be conducted to determine that the normal and emergency brake systems fulfill the requirements of § 25.231.

(iv) Parking brake control (§ 25.735(d)). A demonstration should be made to determine that sufficient braking is provided with the parking brake to prevent the airplane from rolling on a paved, dry, level runway (or any suitable level hard surface) while maximum takeoff power is applied on the most critical engine, with the airplane loaded to maximum ramp weight at aft center of gravity (or the airplane loaded to a weight-c.g. combination that prevents the wheels from sliding). In the case of propeller-driven airplanes, the effects of propeller wash and engine/propeller torque should also be considered in determining the critical engine. Because the resultant thrust vector can be at an angle to a propeller's axis of rotation, one engine/propeller may be more critical than its counterpart on the opposite wing, particularly if all propellers turn in the same direction.

(v) Antiskid devices (§ 25.735(e)).

(A) In addition to meeting acceptable industry specifications, the installation of the antiskid device should comply with the requirements specified in paragraphs (B) and (C) below. The antiskid device and its installation will be approved for use on civil airplanes when the tests specified in the procedures section (see paragraph 55c of this AC) have been satisfactorily demonstrated.

(B) Data required.

(1) An engineering evaluation of the antiskid installation as installed on the airplane, including all necessary components, should be conducted. This analysis and complete descriptive data should be submitted to the FAA. The data should include hydraulic and electrical schematic diagrams of the installation, assembly drawings of antiskid system units, functional hazard analyses, software and hardware substantiations for electronic components, test results or stress analysis substantiating structural strength of attachments and modification of the

axle or other structural members, installation drawings, recommended instructions pertaining to installation, maintenance and operation, and analysis of flight test data and results. Schematic drawings should refer to all units in the normal and emergency brake systems. The engineering evaluation should also assure that the antiskid system does not cause undesirable yaw characteristics.

(2) The engineering evaluation should account for a bounce condition wherein the wheels may leave the runway after the brakes have been applied, for a condition wherein the wheels stay on the runway but the oleos are extended (if the system utilizes landing gear oleo compression in its operation), and for a condition in which the wheels of one main gear may not be in contact with the runway for a considerable time while the wheels of the other main gear are firmly on the runway. If the antiskid installation incorporates the "landing with brake pedals depressed" feature, then this type of operation should also be considered.

(3) It should be shown that the brake cycling frequency imposed by the antiskid installation will not result in excessive loads on the landing gear.

(4) The antiskid equipment should ensure satisfactory braking action on wet and snow/ice-covered runways, as well as on dry, hard-surfaced runways, without additional antiskid adjustments.

(C) Systems requirements. The entire brake system (including both the basic brake system and the antiskid system) should conform to § 25.735. The single failure criterion of § 25.735 should be extended to include the antiskid system. The following should be considered for approval of antiskid systems:

(1) In the event of a probable malfunction within the antiskid system that would result in loss of the antiskid feature on one or more brake units, those brake units affected should automatically revert to normal braking.

(2) A means should be provided so that the pilot or copilot can readily deactivate the antiskid system to prevent loss of all braking capability due to antiskid system malfunctions.

(3) A Failure Mode and Effects Analysis (FMEA) should be provided to evaluate the effect of failures of the antiskid and associated systems (tires, wheels, brakes, etc.) on airplane safety and braking performance. For antiskid systems utilizing "locked wheel protection" circuits, this analysis should include a determination that assures mechanical faults, which could permit the affected axle to continue rotation (e.g., blown tires, broken wheel rims), will not significantly reduce the braking effectiveness of any cross-coupled wheel positions with intact wheels and tires. A tire or wheel failure that results in the loss of additional tires or wheels, either from shrapnel impingement or ensuing overload, should be considered a single failure event.

(vi) Wheel Fuse Plugs.

(A) The hazardous condition of exploding tires and wheels associated with high energy emergency stopping conditions has been greatly alleviated by the installation of wheel fuse plugs. These plugs relieve the tire pressure when the wheel temperatures approach a dangerous limit. The effectiveness of these plugs in preventing hazardous tire blowouts must be demonstrated during a refused takeoff (RTO) test where the brake energy to be absorbed exceeds the maximum landing energy, but not the RTO energy, and the fuse plug must release, thereby deflating the tire(s) before blowout.

(B) An improperly designed blowout plug that allows premature or unwanted release of tire pressure during takeoff or landing could also constitute a hazardous condition. Such a situation would most probably arise during a takeoff from a quick turn-around type of airline operation. Fuse plug integrity should be demonstrated by conducting a maximum landing brake energy (which then becomes the quick turn-around chart limit for the AFM) test, which must not result in a fuse plug release.

(C) Most turbojet transport airplanes have been able to demonstrate wheel blowout plug integrity at a maximum energy level in accordance with the procedures outlined in this section. More restrictive operational limitations (e.g., runway slope and tailwind values) have been imposed to stay within this maximum energy level demonstrated for wheel blowout plug integrity. With the advent of requests to increase the maximum landing weights, and to eliminate these restrictive operational limits, it has been considered acceptable to remove the pertinent restrictions and operational limitations and substitute in their place a chase-around chart as a limitation in the FAA-approved Airplane Flight Manual (AFM). This chart will permit determining whether or not a critical energy level has been exceeded for the operating conditions of altitude, temperature, runway slope, tailwind, and landing weight. When the critical value is exceeded, a statement in the limitations section of the AFM will require that following a landing under such operating conditions, the airplane must remain on the ground a certain length of time prior to taxiing out for takeoff. This length of time will be the time to reach peak wheel temperatures (appropriate to the blowout plug location), plus 15 minutes. In lieu of the AFM fuse plug limitation chart, an alternate method for determining limit operational landing energy, such as a brake temperature limit, can be considered for approval.

* (D) The wear level of the brakes used for the chase-around chart discussed in the preceding paragraph should be selected by the applicant. Service experience indicates that the conservatism contained in the method of determining the turnaround time limits is adequate to allow these limits to be determined using new brakes. *

(E) In the case where it is possible to demonstrate wheel blowout plug integrity at a maximum energy level in accordance with the procedures in this section and without imposing certain restrictions on the operational limitations (e.g., runway slope and tailwind values), it is not considered necessary to incorporate the chase-around chart and pertinent statement in the limitations section of the AFM. Where restrictions are necessary, a pertinent statement and reference to the chase-around chart could be included in the limitations section of the AFM. The chart may be in Section 4, or in an appendix to the AFM.

(vii) Replacement and Modified Brakes.

(A) In order to establish aircraft landing and RTO certification performance levels for a replacement brake or a modified brake, measured accelerate-stop tests, and functional flight tests (landing distance), may be required, depending upon an evaluation of the individual merits of each brake system change. The type and magnitude of flight tests required will depend on whether or not a requested change involves a corresponding change of heat sink and/or torque requirements of the original certificated brake. A review of the change by the cognizant Aircraft Certification Office (ACO) for the type certificate holder is necessary, since original landing gear designs are based on structural analysis, which could be adversely affected by a brake system change. In addition, such tests will also depend on whether or not an increase in the FAA certificated performance level is desired by the applicant.

(B) Changes to the friction couple elements (rotors and stators) are generally considered to be a major change, requiring the testing described in paragraph 55c(1), unless it can be shown that the change cannot affect the airplane stopping performance, brake energy absorption characteristics, or continued airworthiness. Historically, continued airworthiness considerations include such items as landing gear system/airplane vibration control, braking feel, landing gear system compatibilities etc.

(C) Changes to a brake by a manufacturer other than the original TSO holder might be considered to be a minor change, as long as the changes are not to the friction couple elements, and the proposed change(s) cannot affect the airplane stopping performance, brake energy absorption, vibration, and/or thermal control characteristics, and continued airworthiness of the airplane. In certain circumstances, the change to a steel rotor by a manufacturer other than the original TSO holder may be considered to be a minor change, as discussed in paragraph 55c(5)(ii).

c. Procedures. The extent of the flight test requirements, except new airplane certification, may vary depending upon an evaluation of the individual merits of each airplane brake system change, and whether or not an increase in the FAA certificated performance level is desired by the applicant. Past experience has proven that dynamometer tests alone are not considered adequate in determining compliance with this requirement. Flight test procedures for new, replacement, and modified brakes are categorized as follows:

(1) Basic new airplane certification -- complete new design where no airplane performance data exist.

(i) Tests required.

(A) For complete analysis, at least six rejected takeoffs and six landings will normally be necessary.

(1) Six landings must be conducted on the same wheels, tires, and brakes.

(2) All tests should be conducted with engines trimmed to the high side of the normal idle range (if applicable).

* (3) For airplanes whose certification basis includes Amendment 25-92, § 25.101 (i) requires the stopping distance portions of the accelerate-stop and landing distances to be determined with all the aircraft brake assemblies in the fully worn state. An acceptable means of compliance with this requirement is to accomplish the flight test braking tests with less than fully worn brakes, and then correct the test results using dynamometer test data determined with fully worn brakes. It should be substantiated that the dynamometer test methodology employed, and analytical modeling of the airplane/runway system, are representative of actual conditions. *

(B) Additional tests may be necessary for each airplane configuration change (i.e., takeoff and/or landing flaps, nose wheel brakes, antiskid devices inoperative, deactivation of wheel brakes, etc.).

(C) Brake system response evaluation including braking during taxiing (see paragraph 30b(2)(i).

(D) Parking brake adequacy (see paragraph 55c(l)(iii)).

(E) Alternate braking system stops.

(F) Wheel fuse plug evaluation (see paragraph 55c(7)).

(G) Antiskid compatibility on a wet runway.

(H) Automatic gear retraction braking system on airplanes so equipped.

(ii) Maximum rejected takeoff (RTO) energy will be established by conducting an RTO at the maximum brake energy level for which the airplane will be certified. Fires on or around the landing gear are acceptable if the fires can be allowed to burn during the first 5 minutes after the airplane comes to a stop, before extinguishers are required to maintain the safety of the airplane. The condition of the tires, wheels, and brakes can be such that the airplane would require maintenance prior to removal from the runway. A deceleration rate must be maintained during this test that is consistent with the values used by performance scheduling. Tire or wheel explosions are not acceptable. Tire fuse plug releases may occur late in the RTO run, provided directional control is not compromised. The resulting distance (with fuse plugs blown during the RTO run) is to be included in the data used to establish AFM performance, only if it is longer than the data obtained with normal full braking configuration.

* (A) For airplanes whose certification basis includes Amendment 25-92, the maximum brake energy absorption level must be determined for an airplane with all wheel brake assemblies in the fully worn state. In accordance with § 25.109(i), the flight test maximum energy RTO demonstration must be accomplished with all brake assemblies within 10 percent of

their allowable wear limit (i.e., at least 90 percent worn). Dynamometer testing, when used to extend the flight test results to determine the maximum energy absorption capability of the brakes in the fully worn state (i.e., 100 percent worn), should be substantiated as being representative of actual airplane and runway conditions. The fully worn limit is defined as the amount of wear allowed before the brake must be removed from the airplane for overhaul. The allowable wear should be defined in terms of a linear dimension in the axial direction, which is typically determined by measuring the wear pin extension. *

(B) The maximum energy RTO demonstration should be preceded by at least a three mile taxi, with at least three intermediate full stops, using normal braking and with all engines operating.

(C) Landings are not an acceptable means to conduct maximum energy RTO demonstrations. Though permitted in the past, service experience has shown that methods utilized to predict brake and tire temperature increases that would have occurred during taxi and acceleration were not able to accurately account for the associated energy increments.

(iii) The ability of the parking brake to prevent the airplane from rolling should be demonstrated on a paved, dry, level runway (or any suitable level hard surface) with takeoff power applied on the critical engine using the following test procedure:

(A) The airplane should be loaded to its maximum takeoff weight (or the airplane loaded to a weight-c.g. combination that prevents the wheels from sliding) with the tires inflated to the normal pressure for that weight, the flaps should be retracted, the control surfaces centered, and the parking brake set.

(B) Apply takeoff power to the critical engine with the other engine(s) at idle.

(C) Compliance with the requirements of § 25.735(d) is shown if the wheels do not rotate; this is best observed by painting a white radial stripe(s) on the wheels. The airplane may skip, tire tread may shear, or the tire may slip on the wheel, but the parking brake must prevent the wheels from rotating. Skidding of the tires is acceptable.

(2) Addition of New or Modified Brake Design.

(i) This item concerns the addition of a new or highly modified brake design to an existing type certificated airplane for which FAA-approved braking performance test data exists, either for performance credit, or to the existing performance level. A highly modified brake is defined as one that contains new or modified parts that may cause a significant variance in brake kinetic energy absorption characteristics, airplane stopping performance, or continued airworthiness of the airplane . Examples are: significant change in rotor and/or stator lining compound or area, number of stages, piston area, reduction in heat sink weight, changes in total number of friction faces and elements, change in brake geometry (friction, radius, friction area), fuse plug relocation or change in release temperature, heat shield changes that would affect the temperature profile of the wheel and/or fuse plugs, or seal changes.

(ii) Tests Required.

(A) For improved performance credit, all applicable portions of paragraph 55c(1).

(B) For equivalent performance, a sufficient number of conditions to verify the existing approved performance levels (RTO and landing). Consideration should be given to verification of fuse plugs, performance verification at appropriate energy levels, and configuration differences, including antiskid on and off. Taxi tests to ensure that ground handling, maneuvering, and brake sensitivity are satisfactory should be conducted. At least two braking stops, one at heavy weight and one at light weight, should be conducted on a wet runway to verify brake and antiskid system compatibility.

(C) For extended performance, a sufficient number of conditions to define the extended line and determine equivalency to the existing performance levels. Consideration should be given to the items in paragraph (B), above.

(iii) Definitions.

(A) Improved performance implies an increase in the mu versus energy level for the desired operation(s) and may be requested for landing, RTO's, or a specific configuration such as antiskid “on” only.

(B) Equivalent performance implies that sufficient data will be obtained to verify that the performance level for the desired change is equal to or better than the existing performance levels. The change may be for the purpose of changing the c.g. envelope, or for airplane configuration changes (such as flap angles), and may apply to specific operations (such as landings).

(C) Extended performance implies that the existing certification mu versus energy line will be extended to establish the braking force level for a proposed change, such as gross weight or the maximum desired energy level, and may be applied to a specific operation (such as landing only).

(3) Addition of new, or changes to, antiskid systems that may affect airplane performance (e.g., new antiskid system, or a change from coupled to individual wheel control). A sufficient number of airplane performance tests and/or functional tests should be conducted to verify existing approved performance antiskid “on” levels. In the event an increase of braking performance is desired, full airplane performance testing is required.

(4) Fuse plug modification.

(i) Airplane tests for changes to the fuse plugs should be evaluated on a case-by-case basis. While airplane tests are required to establish the initial fuse-plug-no-melt energy, minor changes to fuse plugs or wheel designs may be validated by a back-to-back dynamometer comparison of old versus new designs, provided it is acceptable to the cognizant FAA ACO.

(ii) Airplane tests should be required when a significant change of wheel design and/or redesign or relocation of thermal or pressure fuse plugs is made.

(A) One airplane test should be conducted to show that the fuse plugs will release when excessive energies are absorbed.

(B) Another airplane test is required to verify the maximum kinetic energy at which fuse plugs will not release (fuse plug substantiation). Dynamometer tests are not adequate for this test.

(5) Minor/Major Changes.

(i) Minor brake changes that do not affect airplane braking performance may require functional landings. This may be required to verify airplane-pilot-brake-antiskid combination compatibility. Normally, five non-instrumented, functional landings are considered sufficient to verify this compatibility. Examples of minor changes might include structural improvements (increased fatigue life), adjuster/retractor modifications, material and process specifications changes for structural components, and modified heat-sink relief slots (steel brakes). Examples of other minor changes that do not require functional landings are paint/corrosion changes, changes to bleed ports or lube fittings, revised over inflation devices, metal repair, and salvage procedure. Such changes could be considered to be minor whether they are proposed by the original manufacturer who holds the TSO authorization, or by another manufacturer seeking to produce replacement parts.

(ii) Changes to heat sink friction couple elements are to be considered major changes, unless the applicant can provide evidence that changes are minor. Based upon experience, thicker friction material or heavier heatsink elements are usually acceptable as minor changes in steel brakes. Thicker or heavier heat sink elements in carbon brakes may require additional laboratory and/or airplane testing to assess brake performances and continued airworthiness. Major changes are subject to extensive airplane testing, unless it can be shown that the change cannot affect the airplane stopping performance, brake energy absorption characteristics, and continued airworthiness. In this regard, the original manufacturer of the wheel/brake assembly who holds the TSO authorization, and the Type Certificate holder who is knowledgeable with respect to such items as landing gear design assumptions and airplane braking system history, may possess data sufficient to show that such changes could be considered to be minor (i.e., performance would not be affected). In contrast, an applicant other than the original manufacturer who wishes to produce replacement rotors or stators may not have access to or have established developmental or other test data required to show that performance, braking energy capacities, braking system compatibilities, or overall continued airworthiness safeguards have been addressed. Due to the complex nature of the friction surfaces and airplane braking system interfaces, proposed replacement stators/rotors by an applicant other than the original manufacturer(s) should always be considered a major change.

(iii) It is considered very difficult to determine 100 percent identicality. This is particularly true for brake friction rubbing components (e.g., linings in cups, linings sintered to plates, steels used in steel brakes, and carbon discs in carbon brakes). A finding of equivalence based upon physical documentation and dynamometer testing may not be possible or practical due to friction material complexities and/or the extent of dynamometer testing required.

(iv) Due to the complexities associated with aircraft brake friction couples, industry and authorities have generally discouraged mixing of friction components from various suppliers within the same brake or mixing wheel and brake assemblies from different manufacturers on the same airplane. Typically, the manufacturers of large transport category airplanes have confined the use of specific wheel and brake suppliers assemblies to specific airplanes through approved equipment lists. While multiple wheel and brake suppliers (i.e., multiple original TSO holders) are often selected to provide wheel and brake assemblies on a specific airplane model, intermixing of wheel and brake assemblies has been discouraged to avoid potential problems such as unequal energy sharing; unfavorable dynamic cross coupling between brakes, landing gear, and the airplane; degradation of vibration and/or thermal controls; unique brake control system tuning requirements for each wheel and brake assembly, etc.

(v) The FAA has, however, approved the use of replacement steel rotors. The following protocol for steel rotor equivalency findings has been updated to include brake wear and wear pattern assessments to assure that the worn brake capability of the original manufacturer’s wheel and brake assembly is not degraded by a replacement steel rotor(s). The following criteria and evaluations represent protocol for replacement steel rotors to be considered as a minor change:

(A) a very close correlation between the original part and the proposed replacement part;

(B) considerable and satisfactory prior manufacturing and in-set-vice experience with a similar replacement part;

(C) a reasonable plan of test for completion of the dynamometer portion of the test program;

(D) successful completion of the dynamometer testing; and

(E) as a minimum, successful completion of a series of functional landings on the airplane.

(vi) The necessity of conducting maximum energy RTO testing and other brake system tests on the airplane will depend upon the outcome of the above evaluations and worn brake RTO airplane test experiences (if applicable).

(vii) If intermixing of replacement steel rotors with the original manufacturer's steel rotors is proposed, the applicant must propose an airplane test evaluation plan to the FAA that provides data to guide a worn brake rejected-take-off equivalency assessment. If the applicant cannot provide evidence on similar overall wear and wear patterns from the new to worn condition for the proposed mixing configuration(s), intermixing will not be permitted in order to assure that the worn brake rejected-take-off rating and approved wear limit of the original TSO holders wheel and brake assembly is not jeopardized.

(viii) The dynamometer test plan, and, if applicable, the overall wear and wear pattern test plan, must include:

(A) TSO Minimum Standard Performance Demonstration. The wheel and brake assembly containing the applicant's proposed steel rotor configuration must successfully demonstrate compliance with the braking and structural tests of the applicable TSO, and

(B) Compliance with:

(1) the airplane-manufacturer-specified requirements, or

(2) the alternate procedures specified below:

(ix) Alternate Procedures (steel rotors only).

(A) Energy and Torque Capacity Tests. A series of tests (not only one) may be necessary to demonstrate, in back-to-back tests, that brake energy absorption and torque and pressure vs. time profiles are equivalent. All friction components and structures should be in the new condition to obtain credit for this test. If rebuilt or in-service components other than these fail during testing, it should be realized that the results of the test(s) may be questionable. Suspect tests will be carefully reviewed by the FAA, and may require retesting. Prior to test, the applicant should carefully document wheel hardness and wheel drive, torque tube spline, piston/bushing assembly conditions to assure comparable test articles are being used. The same tire size and ply rating, manufacturer, tire condition, radial load, and rolling radius should be used in each test. Test machines and test conditions must be consistent from test to test, including test brake, wheel and tire break-in stop histories, brake pressure onset rates (psig/sec), maximum pressures, initial brakes-on-speeds, flywheel inertias, etc., to assure consistent test control. Artificial cooling is not permitted during or subsequent to the test until wheel and piston housing temperatures have peaked.

(B) The initial kinetic energy level for this series of tests will be at the discretion of the applicant. For each succeeding run, the KE will be increased by approximately 5 percent over the previous run, until the ultimate KE level is determined (i.e., points at which pistons are about to exit bores or flywheel deceleration falls below 3 ft/sec^2 (½ of the TSO RTO minimum average deceleration requirement)). The deceleration reported by the applicant should be based upon distance (and not time) in accordance with the following formula:

Distance Averaged Deceleration =

((Initial brakes-on speed)^2 - (Final brakes-on-speed)^2)/2(braked flywheel distance).

(1) A minimum of two runs at this ultimate energy level must be conducted on the original manufacturer's wheel and brake assembly for baselines. These test runs must show similar results. Maximum braking force pressure must be applied during the tests. Fuse plug releases in any tests must demonstrate safe release of approved nitrogen-air mixtures.

(2) A minimum of two test runs at the ultimate energy level must then be conducted on the applicant's proposed wheel and brake assembly (i.e., a back-to-back demonstration of the two manufacturers brakes). Tests must show similar brake energy absorption, torque, and thermal performance capabilities, and torque and pressure versus time profiles, while demonstrating sealing and structural integrity comparable to the original manufacturer's wheel and brake assembly.

(C) Worn Brake RTO Capability. Worn brake RTO capability for the proposed wheel and brake assembly with steel rotor replacement configuration(s), and at the wear pin limit(s) proposed by the applicant, must be established during dynamometer test(s). The test brake energy absorption criteria, torque performance , and pass/fail requirements should be requested of the airplane manufacturer to provide supporting evidence that the worn brake RTO capability is equivalent to that achieved with the original TSO holder's wheel and brake assembly(ies). If unavailable, the applicant should propose a worn brake RTO test plan similar to that in paragraph 55c(1) for new brakes. The applicant should also propose to the FAA the method which will be followed by the applicant to verify that the worn brake RTO capability of in-service worn brakes with replacement rotors is equivalent to the capability established in initial dynamometer test(s) in accordance with paragraph 55(c)(1)(ii)(A) of this AC.

(D) Intermixing of steel rotor assemblies produced by two manufacturers will not be allowed until it can be demonstrated that wear patterns of the intermixed assembly(ies), through a determined number of in-service tours, does not jeopardize the worn brake RTO capabilities of the original or the replacement wheel and brake assemblies. Since dynamometer testing is generally impractical, the applicant should forward to the FAA an in-service plan to survey wear and wear patterns from a sampling of worn in-service brakes containing steel rollers from the original manufacturer only, from the applicant only, and from an intermix brake(s). Since the original manufacturer's brake often contains second, and possibly third tour reground steel rotors, at least two tours of in-service evaluation with replacement steel rotors may be required to assess equivalence. This data will provide guidance for approved worn brake RTO wear limits for brakes containing replacement rotors.

(E) Torque/pressure ratio-profiles. A torque/pressure ratio test plan and tests are required to demonstrate equivalent gain performances over a range of test speeds and test pressures. The test article conditions, break-in conditions and procedures, test speed range, and test pressure matrix, used to evaluate both the original and applicant wheel and brake assemblies, must be the same with tests conducted in the same order. The results of these tests will provide guidance for braking system control compatibility assessments.

(F) As a minimum, the five functional landings described in paragraph 55(c)(5)(i), above, are also a required part of this approval procedure.

(G) Continued Airworthiness. Past history with friction material couples has indicated the necessity of ongoing monitoring (by dynamometer test) of RTO capability to assure that the AFM limitations are not exceeded over the life of airplane programs. For larger transport category commercial airplanes, it has been shown that these monitoring plans have complemented the detection and correction of unacceptable deviations. The applicant must provide the FAA with a quality plan to demonstrate that the RTO capability of the friction couple is maintained with replacement steel rotors over time.

(6) Auto-braking. The following are required for auto-braking installations based on function, non-hazard, and non-interference on airplanes for which performance without auto-braking has been determined:

(i) The system design must be evaluated for integrity and non-hazard, including the probability and consequence of insidious failure of critical components. No single failure may compromise non-automatic braking of the airplane.

(ii) Positive indication of whether the system is operative or inoperative must be provided.

(iii) For each auto-brake setting for which approval is desired, the ground roll distance from touchdown to stop must be determined for the landing weights and altitudes within the envelope for which approval is desired. In determining ground roll distance, the performance must be established without reverse thrust, and any adverse effect upon performance associated with the use of reverse thrust must be established and accounted for. Repeatability of initial application should be shown by comparing the onset of braking for each of the range of settings. Landing ground roll distance data determined as prescribed herein must be presented in the performance information section of the FAA-approved AFM as guidance material.

If the auto-braking system is to be approved for wet runways, auto-brake compatibility on a wet runway should be demonstrated. These tests may be limited to the highest auto-brake setting, where antiskid activity is expected to occur throughout the stop, and a single lower setting, where antiskid activity is expected to occur for only a portion of the stop. AFM stopping distances for other settings can be computed based on predicted wet-runway friction coefficients and do not require demonstrations on wet runways of all auto-brake settings. Landing ground roll distance data determined on a wet runway should also be presented in the AFM for all operating modes of the system. This information is considered necessary so that the pilot can readily compare the automatic brake stopping distance and the actual runway length available, so as to assess the effect of the use of the automatic braking system on the runway margin provided by the factored field length.

(iv) Automatic braking systems that are to be approved for use during rejected takeoff conditions should provide only a single brake setting that provides maximum braking. In the event that automatic brakes result in a longer rejected takeoff distance than manual brakes, the FAA-approved AFM must present the longer rejected takeoff distance.

(v) Procedures describing how the automatic braking system was used during the FAA evaluation and in determining the landing ground roll distance of paragraph 55c(6)(iii) must be presented in the AFM.

(vi) Compliance with operational requirements regarding landing runway length will continue to be predicated on landing distance data established using the requirements of § 25.125 for non-automatic braking.

(7) Wheel Fuse Plug Design.

(i) Wheel fuse plug integrity should be substantiated during braking tests where the energy level simulates the maximum landing energy. It should be demonstrated that the wheel fuse plugs wil! remain intact, and that unwanted releases do not occur. One acceptable method to determine this is as follows:

(A) Set engine idle thrust at the maximum value specified (if applicable).

(B) Taxi at least three miles (normal braking, at least three intermediate stops, and all engines operating).

(C) Conduct accelerate-stop test at maximum landing energy, maintaining the deceleration rate consistent with the values used to determine performance distance.

(D) Taxi at least three miles (normal braking, at least three intermediate stops, and all engines operating).

(E) Park in an area so as to minimize wind effects until it is assured that fuse plug temperatures have peaked and that no plugs have released.

(ii) In lieu of simulating the maximum kinetic energy landing during an accelerate-stop test, an actual landing and quick turn-around may be performed; however, caution should be exercised in order to prevent jeopardizing the safety of the flightcrew and airplane if the wheel plugs release right after liftoff, requiring a landing to be made with some flat tires. The following elements should be included in the tests:

(A) Set engine idle thrust at maximum value specified (if applicable).

(B) Conduct a landing stop at maximum landing cnergy, maintaining thc dccclcration ratc consistcnt with the values uscd to dctcrminc pcrformancc distance

(c') Taxi to thc ramp (threc miles minimum with normal braking, at lcast threc intcrniediatc stops, and all cngincs operating).

(D) Stop at thc ramp. Procccd immcdiatcly to taxi for takcoff.

(E) Taxi for takcoff (threc milcs minimum with normal braking, at lcast threc intcrmediatc stops, and all cngincs opcrating).

(F) Park in an arca so as to minimizc wind cffccts until it is assurcd that fusc plug temperatures have peaked and that no plugs have released.

(iii) Fuse plug protcction of wheels and tircs should bc demonstrated to show that thc fusc plugs will release when cxcessivc cncrgics are absorbcd. Normally, this will occur during RTO pcrformancc tcsts.

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